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COLD WATER INJECTION INTO TWO-PHASE MIXTURES

by

Atlantic Nuclear Services Ltd.

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COLD WATER INJECTION INTO A TWO-PHASE FLOW MIXTURE

A research report prepared by Atlantic Nuclear Services Ltd. under contract to the Atomic Energy Control Board.

ABSTRACT

This report presents the results of a review of the international literature regarding the dynamic loadings associated with the injection of cold water into two-phase mixtures. The review placed emphasis on waterhammer in nuclear power plants. Waterhammer incidence data were reviewed for information related to thermalhydraulic conditions, underlying causes and consequential damage. Condensation induced waterhammer was found to be the most significant consequence of injecting cold water into a two-phase system. Several severe waterhammer incidents have been attributed to slug formation and steam bubble collapse under conditions of stratified steam and cold water flows. These phenomena are complex and not well understood. The current body of experimental and analytical knowledge is not large enough to establish maps of expected regimes of condensation induced waterhammer. The Electric Power Research Institute, in the United States, has undertaken a major research and development programme to develop the knowledge base for this area. The limited models and data currently available show that mechanical parameters are as important as thermodynamic conditions for the initiation of condensation induced waterhammer. Examples of bounds for avoiding two-phase waterhammer are given. These bounds are system specific and depend upon parameters such as pump capacity, pipe length and pipe orientation.

RÉSUMÉ

Le présent rapport donne les résultats de l'examen de la documentation internationale sur les charges dynamiques liées à l'injection d'eau froide dans les mélanges diphasiques. L'examen portait principalement sur le phénomène des coups de bélier dans les centrales nucléaires. Les données sur les coups de bélier ont été examinées pour y trouver des renseignements à propos des conditions thermohydrauliques, des causes sous-jacentes et des dommages qui s'ensuivent. On a découvert que les coups de bélier provoqués par la condensation étaient la plus importante conséquence quand on injectait de l'eau froide dans un systéme diphasique. Plusieurs coups de bélier graves ont été attribués à la formation de poches d'eau et à l'affaissement des bulles de vapeur dans des conditions de débits de vapeur et d'eau froide stratifiés. Ces phénomènes sont complexes et mal compris. La somme actuelle des connaissances expérimentales et analytiques ne suffit pas pour dresser des cartes des régimes prévus des coups de bélier provoqués par la condensation. L'Electric Power Research Institute des États-Unis a établi un programme de recherche et développement important pour mettre au point une base de connaissances dans le domaine. Les modèles et les données limités qui sont disponibles pour le moment montrent que les paramètres mécaniques sont aussi importants que les conditions thermodynamiques pour le déclenchement des coups de bélier provoqués par la condensation. Des exemples de bornes pour prévenir les coups de bélier en deux phases sont donnés. Ces bornes sont spécifiques à chaque système et dépendent de paramètres comme la capacité des pompes, ou la longeur et l'orientation des canalisations.

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TABLE OF CONTENTS

1. INTRODUCTION 1

2. WATERHAMMER PHENOMENA 3

2.1 Pressure Transients 3

2.2 Initiating Events 5

3. LITERATURE SURVEY 9

3.1 CAN/OLE Search 9

4. OVERVIEW OF REPORTED WATERHAMMER INCIDENTS 12

4.1 Westinghouse Review 12

4.2 USNRC Compilation of Waterhammer Events 18

4.3 Nuclear Energy Agency (NEA) Incident Reports 25

4.4 Summary of Reported Thermohydraulic Conditions 30
4.4.1 Indian Point 2 30
4.4.2 Browns Ferry 1 30
4.4.3 San Onofre 1 30
4.4.4 Shearon Harris Plant 30
4.4.5 LOFT Reactor 31
4.4.6 Kanupp PK-1 31

5. POSTULATED WATERHAMMER MECHANISMS 32

5.1 Steam Generator Waterhammer 32

5.2 Feedwater System Waterhammer 35

6. WATERHAMMER EXPERIMENTS AND MODELS 39

6.1 Steam Generator Waterhammer Correlation 39

6.2 Feedwater Line Waterhammer 41

6.3 Waterhammer During ECC Injection 41

6.4 Steam Bubble Collapse Waterhammer 47

7. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS 52

7.1 Summary and Conclusions 52

7.2 Recommendations 54

8. REFERENCES 55

9. BIBLIOGRAPHY 57

9.1 United States Nuclear Regulatory Commission 58

9.2 American Nuclear Society 65

9.3 Electric Power Research Institute 71

9.4 American Society of Mechanical Engineers 77

9.5 Miscellaneous (Universitites, journals, etc) 88

LIST OF FIGURES

Figure 1.	Column Separation in a Pump Discharge Line as an Initiating Mechanism for Waterhammer (from Reference 6)	6
Figure 2.	Steam Bubble Collapse Initiating Waterhammer in a Suppression Pool	7
Figure 3.	Entrainment of Water in Steam Flow as an Initiating Mechanism for Waterhammer	7
Figure 4.	Postulated Initiating Mechanism for Steam Generator Waterhammer (from Reference 2)	8
Figure 5.	A Westinghouse Steam Generator Showing the 'Unmodified' Feedring (from Reference 13)	33
Figure 6.	Postulated Sequence of Events Leading to Steam Generator Waterhammer (from Reference 13)	34
Figure 7.	Modified Feedring Design to Reduce Steam Generator Waterhammer (from Reference 13)	36
Figure 8.	Alternative Feedwater Piping Designs to Minimize Steam Generator Waterhammer (from Reference 13)	37
Figure 9.	Filling of a Voided Feedwater Line Causing Waterhammer (from Reference 10)	38
Figure 10.	Slug Impact Pressure as a Function of Driving Head and Void Length (from Reference 25)	40
Figure 11.	Correlation of Waterhammer Initiation with Feedwater Flow and Pipe Length (from Reference 24)	42
Figure 12.	Experimental Layout to Study Cold-Leg Waterhammer [Reference 17]	43
Figure 13.	Steam Bubble Collapse Waterhammer Process in Experimental Flow Model During ECC (from Reference 17)	44
Figure 14.	Measured Waterhammer Pressures During ECC Tests (from Reference 17)	45
Figure 15.	Bounds for Stability Against ECC Initiated Waterhammer for Free 'Overfall' into the Core of a Typical PWR Plant (from Reference 17)	48
Figure 16.	Bounds for Stability Against ECC Initiated Waterhammer as a Function of Water Depth in the Cold Leg of a Typical PWR Plant (from Reference 17)	49

Figure 17. Effect of Geometrical Pressure Losses and Plug Growth on Maximum Obtainable Velocity During Steam Bubble Collapse (from Reference 17) 50

Figure 18. Calculated Waterhammer Pressures as the Result of Steam Bubble Collapse During ECC in a PWR (from Reference 17) 51

LIST OF TABLES

Table 1. Summary of Literature Search 11

Table 2. Westinghouse Review of Waterhammer Incidents Resulting in Damage to Piping Supports 15

Table 3. Overview of Reported PWR Waterhammer Events (1969-1980) from Reference 1 19

Table 4. Overview of Reported BWR Waterhammer Events (1969-1980) from Reference 1 20

Table 5. Overview of BWR Waterhammer Events (1981-1985) from Reference 1 21

Table 6. Overview of PWR Waterhammer Events (1981-1985) from Reference 1 22

Table 7. BWR Waterhammer Events Totals by Damage and Event Class from Reference 3 23

Table 8. PWR Waterhammer Fvents by Damage and Vendor from Reference 3 24

Table 9. NEA-IRS Waterhammer Incidents Resulting in Damage to Piping and/or Piping Systems 27

1. INTRODUCTION

The objective of the study was to review and assess information on dynamic loadings caused by the injection of cold water into two-phase mixtures. To achieve this goal the following five tasks were undertaken:

- A critical survey of the national and international literature of open technical reports concerning the dynamic consequences of cold water injection.
- Documentation of the transients that have been experienced and reported.
- Definition of the thermalhydraulic conditions giving rise to severe dynamic loads on equipment and bounds for the conditions initiating transients.
- Description of the underlying physical processes of the load transients.
- Description of the response of equipment to the severe dynamic loads.

This report presents the findings of the study.

The pressure transients arising from the mixing of steam and subcooled water are referred to generally as waterhammer. There are, of course, many other initiating events leading to waterhammer in nuclear systems. An overview of waterhammer phenomena is given in Section 2.

Waterhammer was identified as an "Unresolved Safety Issue" by the United States Nuclear Regulatory Commission (USNRC) in 1978 and its resolution is described in Reference 1. There were numerous studies and assessments of waterhammer incidents performed in order to resolve the issue. As a result most of the extensive literature on waterhammer in two-phase water systems is based on experience at U.S. nuclear power plants.

A literature survey was undertaken as described in Section 3. The objective was to identify and collect information on the physics of cold water injection into two-phase mixtures and the dynamic response of the systems. The search of databases was comprehensive enough to identify waterhammer, vibration and other dynamic loadings that may be generated in two-phase systems.

The search of CAN/OLE databases, which are maintained by the Canadian Institute for Scientific and Technical Information (CISTI), generated numerous references. They are collected as a bibliography in Section 9. Selected reports of loading conditions that can stress the pressure boundary are reviewed in more detail in the main report. The bibliography has been organized into five major sections according to the agency/association sponsoring the publication. Thus, it consists of the following sections:

- U.S. Nuclear Regulatory Commission (USNRC)
- Electric Power Research Institute (EPRI)
- American Nuclear Society (ANS)
- American Society of Mechanical Engineers (ASME)
- Miscellaneous

The miscellaneous collection covers journal articles, university reports, conference proceedings, etc.

The waterhammer incidents that have occurred in nuclear power plants have been analyzed extensively. In Section 4.0, incident summaries from various sources are collected to present an overview of the systems involved, the consequential damage and the underlying causes. A review by Westinghouse [Ref.2] covers events prior to 1976 while the USNRC studies [Ref.3,4] cover the periods 1969-1981 and 1981-1985. The Nuclear Energy Agency (NEA) database [Ref.5] covers international events from 1980-1988.

The summary of waterhammer incidents includes the assessment of consequential damage. In some instances there have been pipe failures. More generally there has been damage to piping supports and restraints as a result of pipe deflections. Although the reported damage has been significant in many cases, there have been no immediate safety implications for fuel cooling.

There is no generally available method for analyzing and predicting two-phase waterhammer incidents. As a result the reported waterhammer incidents have been treated in an ad hoc fashion. Engineering judgement has been used to assess the events and to make design changes to prevent a recurrence or to mitigate the consequences. In 1987 Kim [Ref.6] outlined the requirements for developing a methodology to analyze two-phase waterhammer.

There have been several incidents involving waterhammer in steam generators and feedwater systems. The underlying mechanisms for slug formation that is believed to initiate the pressure transient is described in Section 5. The design changes that were made as a result of the model are described. Following the design changes the waterhammer incidents decreased lending support to the model.

The evaluation of waterhammer incidents in nuclear power plants stimulated interest in research on two-phase waterhammer. The results of experimental and theoretical programs are reviewed in Section 6. This work provides the only available insight into the range of thermalhydraulic conditions giving rise to two-phase waterhammer.

The report is concluded in Section 7 with a summary of the findings, conclusions and recommendations for further assessments.

2. WATERHAMMER PHENOMENA

Waterhammer is defined to be the transient pressure change occurring in a fluid mechanical system when there is a sudden change in the fluid velocity. In the case of nuclear systems the fluid will be water, steam or a steam-water mixture. The conversion of kinetic energy to pressure or pressure to kinetic energy results in either a compression wave or a rarefaction wave, respectively.

Waterhammer in systems containing only water has been well understood for some time [Ref.7]. The systems are designed to accommodate the waterhammer resulting from the normal operation of equipment. For example, anticipated waterhammer loads include the pressure transients resulting from the opening and closing of flow control valves.

Waterhammer will also occur under abnormal operating conditions that are not anticipated. The systems are not designed to accommodate the pressure loads for such cases.

In general a waterhammer event can be described by three distinct elements:

(i) Initiating Event - The initiating event that causes the change in fluid velocity.

(ii) Forcing Function - The dynamic description of the pressure transient within the system.

(iii) Consequential Damage - As the pressure wave propagates through the system, unbalanced loads at the system boundary can damage components and equipment.

In the past twelve years there has been a considerable number of studies of waterhammer events in nuclear power plants. Nuclear plants are complex systems containing water, steam or steam-water mixtures at high pressures and temperatures. The types of waterhammer phenomena in two-phase systems are well known. However, the forcing functions are not as readily describable as in the case of single phase systems.

The following sections provide an overview of pressure transients and their initiating events.

2.1 Pressure Transients

The potential pressure change in a liquid filled system is given by (likewise for steam)

$$\Delta P = a_\ell \, \rho_\ell \, u_\ell \qquad (2.1)$$

where a_ℓ = sound velocity in the liquid

ρ_ℓ = liquid density

The change in pressure propagates through the system with the velocity of sound corrected for the elasticity of the confining structures. At standard temperature and pressure the sound speed in water is about 1440 m/s. This is reduced by as much as 10-30 percent in small to large diameter steel conduits [Ref.7].

Entrained air in water has the effect of reducing the sound speed. The reduction is very rapid for small amounts of air and is about 50 percent with 10 percent air by volume [Ref.7].

In analogy with Eq.2.1, the potential pressure change in a two-phase fluid is given by [Ref.8]

$$\Delta P = C_{tp}\, \rho_{tp}\, u_{tp} \qquad (2.2)$$

where C_{tp} = the speed of propagation of the pressure wave in the two-phase fluid

ρ_{tp} = average density of the two-phase fluid

u_{tp} = average initial velocity of the two-phase fluid

It is important to note that the speed of propagation for the pressure wave C_{tp} is not the sound speed in the two-phase liquid.

In a steam-water mixture the propagation speed for a pressure wave depends upon the pressure and void behind the wave front. That is, the speed of the wave depends upon the magnitude of the disturbance. The sound speed, which is the propagation speed of an infinitesimal disturbance, depends upon the pressure in front of the wave and is a characteristic of the undisturbed fluid conditions alone.

If there is a phase change across the wavefront the speed of propagation is slower than if there is no condensation/evaporation. Assuming no mass or heat transfer between the two phases, the wave speed and sound speed are related by [Ref.8]

$$C_{tp}/a_{tp} = (P_{<}/P_{>})^{\frac{1}{2}} \qquad (2.3)$$

when a_{tp} = two-phase sound speed

$P_{<}$ = pressure behind the wavefront

$P_{>}$ = pressure in front of the wavefront

The wave speed in two-phase water mixtures is a few hundred m/s depending upon fluid conditions and the magnitude of the disturbance. Also, the speed will change as the local void conditions vary along a conduit.

Comparing Equations 2.1 and 2.2 it is apparent that the magnitude of potential pressure changes is generally less for steam-water mixtures than for water. An exception to this is the acceleration of water slugs by void collapse which is discussed below.

2.2 Initiating Events

There are several types of initiating events that can cause a sudden change in flow speed and generate a pressure transient. The following occur in single and/or two-phase systems.

(i) Valve Opening/Closing - A rapid opening or closing of a valve to control flow can give rise to excessive dynamic loads. This includes check valve closure in response to abnormal conditions such as a pipe rupture and stuck check valves that are suddenly released.

(ii) Pump Start/Stop - The starting or stopping (or seizure) of a pump will change the flow velocity. Pump startup with full discharge lines does not normally pose a problem. However, discharge into empty lines can cause excessive forces. The sudden reduction in flow because of a pump seizure will create waterhammer. Under some conditions the stopping or seizing of a pump may result in cavitation and significant dynamic loads.

(iii) Empty Lines - Any line that is normally empty when flow is initiated has the potential for excessive dynamic loads. This will normally occur upon a pump startup or a valve opening.

(iv) Cavitation (Column Separation) - Low pressure transients can lead to vapour formation and the subsequent collapse of the voids can cause significant waterhammer.

(v) Steam Bubble Collapse - In steam-water mixtures under non-equilibrium conditions, steam bubbles may be condensed rapidly enough to alter the flow speed and cause waterhammer. This can happen when mixing steam and water from two systems or from pressurization and condensation.

(vi) Slug Impact - Stratified flow conditions may be unstable and lead to steam bubbles being formed and rapidly condensed. This results in the acceleration of slugs of water and impact on water columns and elbows. Large dynamic forces can be generated.

(vii) Water Entrainment - Residual water in steam lines will be accelerated by the steam flow. The impingement of the water slugs on elbows or other flow obstructions may cause significant dynamic loads.

All the above mechanisms can cause waterhammer in nuclear systems. Cavitation, steam bubble collapse, slug impact and water entrainment are unique to the two-phase character of the systems. Apart from water entrainment, condensation is the primary driving mechanism in two-phase systems. Steam bubble collapse and slug impact are of particular interest for this study since they are caused by steam condensing upon contact with subcooled water.

Figures 1-4 illustrate the two-phase waterhammer initiating mechanisms. Separation of a water column following the stopping of a pump is illustrated in Figure 1. The collapse of the vapour gas when the pump is started will cause waterhammer.

Pressure suppression systems offer an example of steam bubble collapse as illustrated in Figure 2. Steam is injected into a subcooled pool of water and condensed. The collapse of the steam bubble will generate pressure waves.

The entrainment of water in steam flows is illustrated in Figure 3. For example, this can occur if residual water is not drained from the main steam lines before startup.

Figure 4 illustrates a slug formation mechanism believed to occur in the feedring of PWR steam generators.

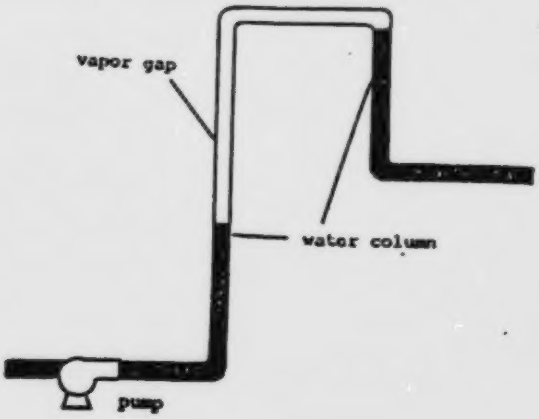


Figure 1. Column Separation in a Pump Discharge Line as an Initiating Mechanism for Waterhammer (from Reference 6)

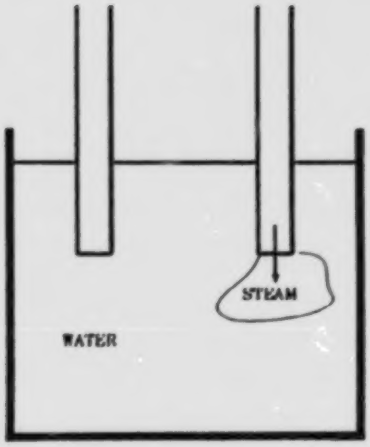


Figure 2. Steam Bubble Collapse Initiating Waterhammer in a Suppression Pool

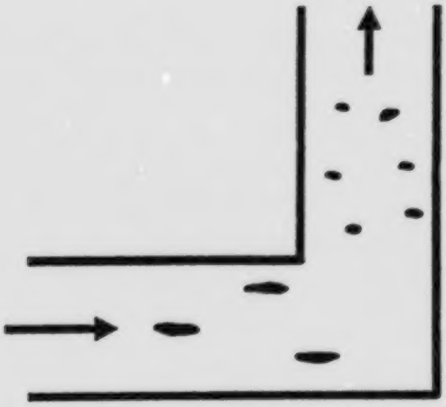


Figure 3. Entrainment of Water in Steam Flow as an Initiating Mechanism for Waterhammer

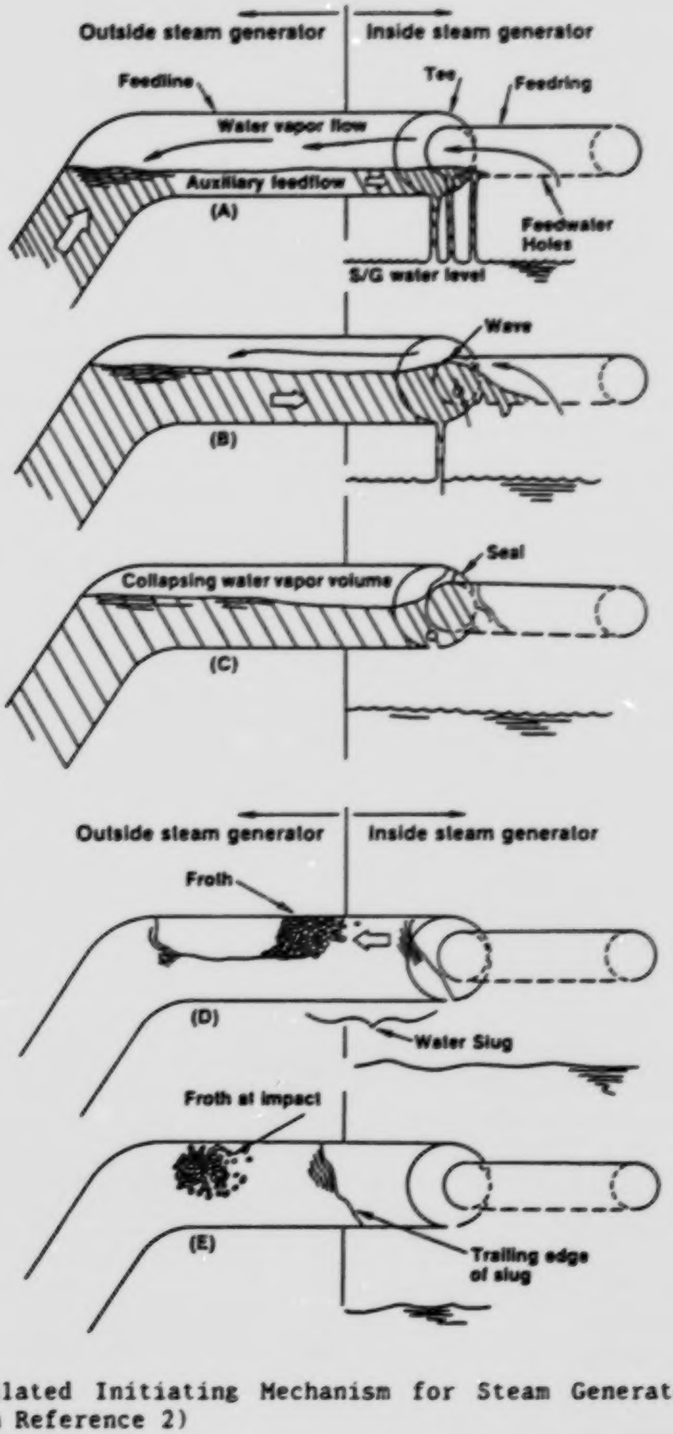


Figure 4. Postulated Initiating Mechanism for Steam Generator Waterhammer (from Reference 2)

3. LITERATURE SURVEY

A literature survey was undertaken to identify work that has already been done in the area of cold water injection in two-phase flow mixture. The primary search was with the CAN/OLE system of the Canadian Institute for Scientific and Technical Information.

3.1 CAN/OLE Search

Six of the CAN/OLE databases were searched with the following literature coverage.

(i) Engineering Index (EI)

The EI database, produced by Engineering Information, Inc., covers all aspects of engineering and related technology areas. More than 4,500 primary international publications are covered from 1970 to date. Subject areas relevant to the current project include:

- Mechanical Engineering
- Nuclear Technology
- Heat and Thermodynamics

(ii) Information Services in Physics, Electronics and Computing (INSPEC)

Information Services in Physics, Electronics and Computing (INSPEC) is produced by the Information Services Division of the Institution of Electrical Engineers (UK) and provides worldwide coverage on all aspects of physics, electrical engineering, electronics, computers, control engineering and information technology. The database covers journals, conference proceedings, monographs, theses, technical reports, and patents (1970-76). From 1970 to date. Subject areas relevant to the current project include:

- Fluids, Plasmas
- Nuclear Physics
- Power Systems

(iii) National Technical Information Service (NTIS)

The NTIS database, produced by the National Technical Information Service of the United States Department of Commerce, is a multidisciplinary database representing US government sponsored research, development, engineering reports and machine processable data files and related software. The reports originate from over 300 US government departments and agencies, including NASA, Dept. of Defense, Dept. of Energy, Dept. of Health, Education and Welfare, the Environmental Protection Agency and the Dept. of Agriculture. The database covers US government reports, government sponsored translations, foreign language reports and US government owned patents from 1964 to date. Subject areas relevant to the current project include:

- Energy
- Engineering
- Nuclear Science and Technology

(iv) EI Engineering Meetings (EIM)

The EIM database, produced by Engineering Information, Inc., complements the EI database by providing in depth coverage of 2,000 technical conferences held each year and their contribution of 100,000 papers. Publications are covered from July 1982 to date. Subject areas relevant to the current project include:

- Mechanical Engineering
- Nuclear Technology
- Heat and Thermodynamics

(v) Electric Power Database (EPD)

The EPD database, produced by the Technical Information Centre of the Electric Power Research Institute, contains summaries of research and development projects of interest to the electric power industry in Canada and the United States. Ongoing and completed research projects in both the public and private sectors are covered from 1972 to date.

(vi) International Nuclear Information System (INIS)

The INIS database, produced by the International Atomic Energy Agency, provides worldwide coverage of all aspects of nuclear science and technology used for peaceful purposes. INIS covers approximately ninety-five percent of the world's literature in the field. It covers journals, theses, conference proceedings, books, reports and patents from 1970 to date. Subject areas relevant to the current project include:

- Engineering and Technology
- Nuclear Reactors

Eleven search strategies were used for keywords in the literature review. Search strategy 11 was not successful in producing relevant citations. Search strategies from 1 to 9 proved more successful. The majority of relevant citations, however, were produced by search strategy 2. Table 1 summarizes the results of the literature survey performed using the CAN/OLE system.

Table 1. SUMMARY OF LITERATURE SEARCH

St. #	Keyword Searched	No. of References					
		Databases Searched					
		NTIS	EI	EIM	EPD	INSPEC	INIS
1.	Waterhammer OR Water Hammer	119	342	172	14	91	215
2.	(Waterhammer OR Water Hammer) AND Nuclear	42	9	37	8	20	63
3.	((Pressure Vessel OR Piping) AND Integrity) AND Two-Phase	35	45	28	8	0	0
4.	Pressure Transients AND Damage	6	1	3	0	5	3
5.	Two-Phase AND Vibration	25	18	13	5	12	3
6.	Pumps AND (Pressure OR Flow Transients)	0	0	3	1	0	0
7.	Pressure Suppression AND Loading	3	0	3	1	4	23
8.	Two-Phase AND Dynamic Loads	0	0	0	0	1	25
9.	Steam Bubble Collapse OR Void Collapse	4	7	0	0	19	15
10.	Condensation, Nuclear AND System	9	0	0	0	0	0
11.	Two-Phase, Tank AND Loading	0	0	0	0	0	0

4. OVERVIEW OF REPORTED WATERHAMMER INCIDENTS

This section presents the results of the literature review of reported waterhammer events in all fluid systems of the nuclear power plants that could have an impact on plant safety. Only incidents resulting in damage to plant components are included in this report. In the following sections waterhammer incidents are presented under the reporting system/agency from which the information was obtained. The data are summarized to show the systems involved, initiating mechanisms and consequential damage.

4.1 Westinghouse Review

Waterhammer incidents included in this section are taken from the Westinghouse review of waterhammer in operating nuclear power plants up to 1976 [Ref.2]. The following are typical desciptions of events that resulted either in piping or piping supports damage.

1. Calvert Cliffs Unit 1: Waterhammer Damage Valve Operator Failure, Steam Generator Feedring Modification (May 1975)

"The plant was on hot shutdown following a reactor trip resulting from a loss of feedwater. No. 12 feedwater pump had tripped due to low suction pressure. About 40 minutes after the trip, three waterhammers were experienced in the feedwater piping. Damage to the motor operators of both feedwater header stop valves occurred rendering them inoperable. The manual handwheel for the no. 11 header stop valve was also damaged such that the valve could not be operated manually. The quenching of steam voids formed in the feed header while reestablishing steam generator levels following the trip apparently caused the waterhammer reaction.

Damage was extensive, ranging from pipe that had taken a permanent set of ~ 1½ inches to broken motor mount transition pieces on the feedwater control valves. It appeared that both feedwater lines suffered waterhammer; however, the extent of the damage was greater on no. 12 feedwater line than on no. 11.

Inside the auxiliary building both Limitorque motor operators from no. 11 and no. 12 feedwater isolation valves experienced complete failure. Each motor operator housing was severed at the same location under the waterhammer impact load. At the location of the break, the housing casting was ~ 12 inches in diameter with a variable wall thickness ranging from 3/4 to 2 inches. In addition to the housing failure on no. 12 valve, the spoked handwheel was severed from the hub. This indicated impact in two directions.

The extent of the observed damage and plastic deformation in the no. 11 feedwater line identified the need for thorough non-destructive testing (NDT)."

2. Indian Point Unit 2: Waterhammer Damage - Feedwater Piping Failure, Steam Generator Blowdown (Nov 1973)

"The Indian Point Unit 2 reactor was at 7 percent power during startup following a maintenance outage. The steam generator water level was maintained with the auxiliary feedwater system. However, difficulty with this system resulted in steam generator level fluctuations. A high steam generator level resulted in a turbine trip which caused some overcorrection resulting in a low level and a low-low level reactor trip. This trip initiated auxiliary feedwater start in the emergency mode. The resulting cold auxiliary feedwater injection into the no. 22 steam generator while the indicated level was below the feedwater distribution ring resulted in a waterhammer surge indicated by an audible impact and a large fluctuation in pressure.

With the auxiliary feedwater system operating, levels were restored in all but no. 22 steam generator. The level continued to decrease indicating that sufficient flow was apparently not reaching the steam generator. The operator made several checks including verifying system line-up, auxiliary feedwater regulating valve operation, and discharge pressure. None of these efforts were successful.

At about 50 minutes after turbine trip, a second waterhammer accompanied by a loud noise was observed in no. 22 feedwater line by operating personnel in the auxiliary feed pump building. At 90 minutes, several indications of leakage inside containment were observed by plant operators. The level in the waste holdup tank increased. The discharge valves for the containment sump pumps were shut and the containment sump level indicators were checked. After another 15 minutes, there were indications of a rising sump level and the sump pump valves were then put back in the normal position. Containment temperature increased to a maximum of 110°F (43°C). Three of the five containment recirculation fan coolers were in service at the time. The two other fans were then placed in service, and additional cooling water was supplied by opening the bypass around the temperature control valve. The containment humidity recorder also indicated increased humidity in containment to a wet-bulb temperature of ~90°F (32°C), and the containment recirculation fan cooler units condensate collection system weirs indicated rising levels. At this point, the main steam isolation valves on no. 22 steam generator and the manual isolation valve upstream of no. 22 feedwater regulating valve were shut.

Based on the observations, analysis, and tests, mechanisms were identified which could have developed sufficient energy to cause the piping failure or could have contributed to the failure. These were:

- Waterhammer caused by the sudden closure of the feedwater regulating valve
- Water slug loading caused by check valve malfunction which results in feedline backflow from the steam generator and subsequent quench of steam voids

- Water slug loading caused by water/steam reaction in the horizontal feedwater line adjacent to steam generator no. 22 which followed the uncovering of the steam generator feedring and partial drainage of the connected feed piping"

Table 2. WESTINGHOUSE REVIEW OF WATERHAMMER INCIDENTS RESULTING IN DAMAGE TO PIPING SUPPORTS

Item #	Plant	Systems Involved	Damages	Date
1.	Calvert Cliffs	Feedwater Piping	Piping deformation and valve mounts	May 1975
2.	Turkey Point 4	Feedwater Piping System	Piping Supports by Seismic Shock Arresters	Early 1974
3.	Surrey Unit 1	Main Feedwater System	- Rupture of feedwater check valve - Seven Spring Hanger Broken - Two Sliding Supports Damaged - Seven Hydraulic Snubbers Broken	October 1972
4.	Indian Point 2	Feedwater System	Feedwater Pipe Fractures	May 1973
5.	Beznau 1	Feedwater System	- Four Broken Instrument Lines on the Steam Piping - Three Major Hangers Torn Out of Concrete Anchors	July 1969
6.	Indian Point 1	De-aerator Piping	Cracks in the Main Condensate Line	1970
7.	Zion 1	Auxiliary Feedwater Pump Turbine Exhaust Drain	Exhaust Pipe Hanger Broke	June 1974
8.	Surry 2	Safety Injection Accumulator Discharge Lines	Piping Supports	1974
9.	San Onofre 1	Safety Injection Piping	Safety Injection Valve Disabled	October 1973

10.	Dresden 3	Core Spray System Piping	Core Spray Valve	November 1974
11.	Quad Cities 1	Residual Heat Removal System Piping	Seismic Restraint and Pipe Hangers Damaged	April 1972
12.	James A. Fitzpatrick	Residual Heat Removal System Piping	Pipe Restraint Damaged	July 1975
13.	Browns Ferry 1	High Pressure Core Injection (HPC1) System	- Three Vertical Pipe Hanger Rods - Two Wall Restraints Bent - One Hydraulic Restraint Clevis was Sheared Off	April 1974
14.	Duane Arnold	High Pressure Core Injection Piping	- Insulation at pipe flexure locations - Seismic Snubber - an HPC1 steam supply line drain pot level instrument	June 1974
15.	Connecticut Yankee	Feedwater Piping	Piping Supports and Snubbers Damaged	June 1975
16.	Yankee Rowe	Feedwater System	Damage to Steam Generator Feedwater Ring	Mid 1966
17.	Mihama 2	Feedwater System	Piping Supports Damaged	October 1971
18.	Palisades	Low Pressure Safety Injection	Pipe Restraint Damage	May 1974
19.	Millstone	Condenser	Failure of Header End cap	1972
20.	Dresden 2	Core Spray System	Piping Restraint and Hangar Damage	1971

21.	Dresden 2	Core Spray System	Valve Operator Damage	March 1971
22.	James A. Fitzpatrick	Containment Spray System	Pipe Restraints Damaged	March 1975
23.	Dresden 2	High Pressure Core Injection	Pipe Deformation and Restraint Damage	May 1970
24.	Dresden 3	Feedwater System	Valve and Pipe Support Damage	June 1974

4.2 USNRC Compilation of Waterhammer Events

Serkiz has presented an overview [Ref.1] of waterhammer events identifying the underlying causes. His data (see also Reference 4) is given in Tables 3-6.

A more detailed review of waterhammer incients between 1969 and 1981 is given by Chapman, et al [Ref.3]. They identify four basic bypes of initiating events:

- Water column separation in liquid flows
- Flow into voided (or partially voided) lines
- Steam bubble collapse or mixing of subcooled water and steam from interconnected systems.
- Water entrainment in steam lines

A total of 81 boiling water reactors (BWR) and 67 pressurized water reactors (PWR) waterhammer events were reported [Ref.3]. Table 7 and 8 summarize the events according to consequential damage. For both PWRs and BWRs half of the event reports indicated that damage occurred in the piping support systems. A third of the event reports indicate damage to piping related systems. These systems include those portions of piping that could lead to coolant leakage if there were extensive damage.

For the present study only those waterhammer events initiated by steam bubble collapse or slug acceleration are of interest. Of the 188 reported events between 1969 and 1985, 45 were identified as being due to steam bubble collapse or slug formation. Of these 45 events, 27 were due to steam bubble collapse and slug formation in the feedring of steam generators. Design fixes (see section 5) were made and no incidents were reported in the 1981-85 period.

Reference 9 gives a detailed evaluation of the waterhammer incidents up to 1989. It includes recommendations for design and operation for the prevention or mitigation of waterhammer transients.

An overview of incidents between 1981 and 1985 is given in Tables 5 and 6. Eighteen of the reported events occurred at BWRs and 22 of the events occurred at PWRs.

The results in Table 5 indicate that the BWR systems most susceptible to waterhammer continue to be the residual heat removal (RHR) and high-pressure coolant injection (HPCI) systems. Flow into voided (or partially voided) lines and steam-water entrainment continue to be the most frequently cited underlying causes for BWR waterhammer events. The results in Table 6 show that the PWR systems most susceptible to waterhammer are the feedwater system and the steam generators. Again, line voiding and steam-water entrainment continue to be the most frequent waterhammer initiating mechanisms.

Table 3 Overview of reported BWR Waterhammer Events (1969-1980) from Reference 1

System	NO. of Events	Underlying Cause
Core spray (CS)	9	Voided lines
Residual heat removal (RHR):		
Shutdown cooling	7	Voided lines (11), steam bubble collapse (8),
Reactor vessel head spray	1	Steamwater entrainment
Containment spray	4	Steamwater entrainment (1), unknown (3)
Low-pressure coolant injection (LPCI)	1	
Fuel pool cooling	3	
Steam condensing	7	
High-pressure coolant injection (HPCI)	20	Steam-water entrainment (12), steam bubble collapse (4), voided lines (3), unknown (1)
Cooling water	9	Voided lines (5), design and procedures (2), water column separation (2)
Main steam	6	Steam-water entrainment (2), valve operation (4)
Isolation condenser	4	Steam-water entrainment
Feedwater (FW)	3	Valve controller instabilities
Condenser	3	Maintenance and design errors
Reactor core isolation cooling (RCIC)	2	Steam-water entrainment (1)
Reactor water cleanup	1	Unknown
Plant process steam	1	Steam bubble collapse
TOTAL	81	

Table 4 Overview of reported PWR Waterhammer Events (1969-1980) from Reference 1

System	No. of events	Underlying cause
Feedwater	13	Control valve instabilities
ECCS safety injection	4	Voided lines (3), steam bubble collapse (1)
Reactor primary system	5	Relief valve discharge
Cooling water	3	Voided lines (2), unknown (1)
SGs	27	Top feedring drainage followed by steam bubble collapse and water slug formation
Main steam	8	Valve closures/openings (4), steam-water entrainment (3), relief valve discharge (1)
RHR	1	Incorrect valve alignment causing voided line
Chemical and volume control (CVC)	2	Voided line, steam bubble collapse
Condenser	4	Design and procedures
TOTAL	67	

Table 5 Overview of BWR Waterhammer Events (1981-1985) from Reference 1

System	No. of events	Underlying cause	Comments
RHR			
Shutdown cooling	4	Procedures (1), voided lines (3)	Isolation valve leakage (1)
LPCI	1	Unknown	
Pool cooling	1	Unknown	
Condensing	1	Unknown	
HPCI	5	Design and procedures (2), steam-water entrainment (1), voided lines (1), unknown (1)	
Main steam	1	Steam-water entrainment	Inadequate draining procedures
CS	1	Unknown	
Isolation condenser	1	Steam-water entrainment	Inadequate draining procedures
Service water	3	Voided lines (3)	Procedures (2)
TOTAL	18		

Table 6 Overview of PWR Waterhammer Events (1981-1985) from Reference 1

System	No. of events	Underlying cause	Comments
FW	4	Unknown (1), steam bubble collapse (1), voided lines (1), procedures (1)	Stuck-open check valve at Salem-2 (4/6/84)
SG	4	Unknown (1), procedures (2), voided lines (1)	Line voiding due to check valve leakage at SONGS-1 (11/21/85)
RHR	3	Voided lines (3)	Inadequate procedures (1), isolation valve leakage (1), design deficiency (1)
SG blowdown piping	3	Voided lines (1), procedures (1), unknown (1)	Isolation valve leakage (1)
CVCS	2	Voided line (1), steam bubble collapse (1)	Maintenance error (1)
Steam supply to auxiliary feed pump	3	Steam water entrainment (3)	Drain pot operation (2), failed heat tracing (1)
Main steam	1	Steam water entrainment	Operator error
Steam supply to main feed	1	Steam water entrainment	Drain pot operation
Service water	1	Voided lines	
TOTAL	22		

Table 7. BWR WATERHAMMER EVENT TOTALS BY DAMAGE AND EVENT CLASS FROM REFERENCE 3

Items Damaged	Events by Event Class					
	Class I		Class II		Class III	
	#	%	#	%	#	%
Snubbers, Supports, Snubber/Support	10	35	7	54	14	36
Supports/Snubbers/Piping	3	10	[illegible]	-	1	3
Supports/Snubbers/Misc.	4	14	-	-	-	-
Supports/Valves	1	3	-	-	1	3
Valve, Valve Switch	-	-	1	8	4	10
Piping, Pumps, and Related	8	28	2	15	13	33
Coolant Release to Canal	-	-	-	-	1	3
Pedestal, Insul	-	-	-	-	3	8
Unknown, No Damage, not Indicated	3	10	3	23	2	5
Total	29	100	13	100	39	100
Snubber, Support Related	18	62	7	54	16	41
Piping Related	8	28	3	23	21	54

Classes of events are defined in the following:

Class 1: Events occurred prior to a plant's commercial operation date.

Class 2: Events occurred within one year after a plant's commercial operation date.

Class 3: Events occurred after the first year of a plant's commercial operation.

Table 8. PWR WATERHAMMER EVENTS BY DAMAGE AND VENDOR FROM REFERENCE 3

Items Damaged	Events by NSSS Vendor					
	W		CE		BSW	
	#	%	#	%	#	%
Snubbers, Supports Snubbers/Supports	9	33	1	20	4	50
Supports/Snubbers/ Piping Related	2	7	-	-	-	-
Supports/Snubbers/Misc	2	7	-	-	-	-
Supports/Valve	2	7	-	-	-	-
Valve	1	4	1	20	-	-
Piping and Related	6	22	2	40	1	13
Coolant Release/ Rupture Disc	1	4	-	-	1	13
Insul, Grout, Plate	1	4	-	-	-	-
Unknown, No Damage, Not Indicated	3	11	1	20	2	25
Total	27	100	5	100	8	100
Snubber, Support Related	15	56	1	20	4	50
Piping Related	9	33	3	60	2	25

4.3 Nuclear Energy Agency (NEA) Incident Reports

The NEA - Incident Reporting System (IRS) covers incidents that occurred from January 1980 to February 1988 [Ref.5]. Most of the incidents reported under the NEA -IRS reporting system resulted in either damage to piping supports and restraints or no damage at all. Only a few cases involved small cracks or ruptures in piping systems as described below.

1. Maine Yankee: Maine Feedwater Line Break Due to Waterhammer (January 1983)

On January 25, 1983, the Maine Yankee Nuclear Power Plant experienced a reactor trip followed by loss of main feedwater and automatic initiation of the auxiliary feedwater system. The auxiliary feedwater initiation resulted in a waterhammer transient in the feedwater lines for two of the three steam generators with a resultant feedwater pipe rupture.

2. Kanupp Pk-1: Steam Line Rupture (Steam Drain Water Line Elbow and Tubing) During Plant Start-Up (February 1986)

Reactor was operating in low log mode with 0.9% rated power and primary heat transport system warm-up was in progress. PHT temperature was 414°F (212 °C) and steam pressure was around 325 psig (2.24 MPa(g)). Steam header drain valves were opened and the drains were directed to Blowdown Tank. Main steam line traps were lined-up and their by-pass valves were ½ turn open.

When the steam pressure reached 325 psig (2.24 MPa(g)), heavy hammering was observed in steam lines in condenser area. Valve line-up was checked thoroughly and was found normal. However, steam trap by-pass valves were opened one more turn to facilitate draining of water from main steam lines. After about 10 minutes, steam was observed to be blowing down from a cracked elbow of SDW line near valve SDW-V202. Soon after a transmitter tubing also got disconnected from its take off point in the steam transmitters room.

3. Kalpakkam 1: Burst in Fire Fighting System Line (Nov 1984)

During a functional test, when a valve in the emergency injection fire water line to boiler feed water system was opened, high pressure hot water at feedwater system pressure caused waterhammering and subsequent bursting of a spool piece in the cast iron line located underground near the fire water pump house. All the fire pumps started on auto. They were stopped. Fire water system was subsequently filled up with Jockey pump, vented and normalized. PHT system was cooled to less than 100°C. The damaged spool piece location was isolated to facilitate replacement. The blown out spool piece was replaced.

4. San Onofre Unit 1: Loss of all in-plant AC Power Event at San Onofre 1. (Nov 1985)

The plant was operating at 60 percent power with one vital bus being provided with offsite power through the "C" auxiliary transformer. This transformer developed an electrical fault resulting in the loss of this vital bus. Control room operators responded by manually scramming the reactor pursuant to procedures for loss of a vital bus. The main generator was then tripped which resulted in the loss of all in-plant AC power. As designed, the diesels started, but did not automatically energize the emergency buses. Operators restored in-plant power from the switchyard in about four minutes.

Following the reactor scram, a waterhammer occurred associated with the "B" steam generator which is believed responsible for a sizeable feedwater leak that could not be isolated because of the environmental conditions at this location. This leak was from a check valve in the bypass line for the "B" steam generator feedwater regulating valve. Other failures during this event included a ruptured feedwater heater.

Table 9 summarizes the waterhammer events from the NEA System that resulted in damage either to piping/feedwater systems or piping supports and restraints. This listing includes several non - U.S. incidents. However, the underlying causes appear to be similar to the U.S. experience.

Table 9. NEA-IRS WATERHAMMER INCIDENTS RESULTING IN DAMAGE TO PIPING AND/OR PIPING SUPPORT SYSTEMS

Item #	Plant	System Involved	Damages	Date
1.	Main Yankee	Main Feedwater Line	Pipe Rupture	January 1983
2.	Kanupp Pk-1	Steam Line	Rupture of Steam Drain Water Line	February 1986
3.	Kalpakkam 1	Fire Fighting System Line	Bursting of a Spool Piece in The Cast Iron Line Near Fire Water Pump House	November 1984
4.	San Onofre 1	"B" Steam Generator	Rupture of Feedwater Heater	November 1985
5.	Salem 1	Feedwater Piping and Condensate System	Pipe Hangers, Instrumentation and Insulation Damage	April 1984
6.	McGuire 2	Residual Heat Removal System	Support Restraints Damaged	August 1984
7.	Doel 2	Feedwater Thermal Liners in Steam Generators	Erosion of Thermal Liners	September 1985
8.	Goesgen CH-4	-Main Steam and Auxiliaries -Condensate and Feedwater	-Pipe and Component Supports -Several Valve Position Motors Broke off	February 1980
9.	Davis Besse 1	-Steam Generator, Boiler -Auxiliary Feed-Water	-Heat Exchangers, Fittings, Couplings, Hangers, Supports Bearings, Snubbers, Thermal Sleeves	April 1982

10.	Rancho Seco 1	-Steam Generator, Boiler -Auxiliary Feedwater	-Header Deformation on the Outside Face -Two Pins were Bent -The Bottom Ligament of one Bracket was torn out	April 1982
11.	Oconee 3	-Steam Generator, Boiler -Auxiliary Feedwater	-Header Deformation in the B Steam Generator -Steam Generator Headers had Bent Brackets and Missing Pins	April 1982
12.	Oyster Creek	-Condenser and Feedwater -Reactor Water Cleanup	-Valves, Valve Operators, Controllers, Dampers, Seals	December 1982
13.	Bruce 2	-Turbogenerator and Auxiliaries	-Violent Pipe Motion -Shearing off Two Valves, Pipe Weld Failure	January 1983
14.	Bruce 4	-Steam Generator, Boiler -Low Voltage AC -Vital Instrumentation AC and Control AC -Condensate and Feedwater	-Pipe Between the Deaerator and the Last Stage of the Low Pressure Feedwater Heaters was Plastically Deformed -Extensive Weld Fractures at the Divider Plates of Low Pressure Feedwater Heater -Pipe Restraints -Loosened Hangers -Removed Flow Straightener	March 1983

15.	Salem 2	-Condensate and Feedwater -Feedwater Control	-Major Distortion of the Piping Support Systems -Distortion of a Cam Positioner of a Control Valve and a Position Transmitter of a by-pass Valve -Distortion of a Trunious on the Feedwater Piping in Containment -Plugging of a Flow Transmitter Line with Rust Buildup	April 1984
16.	Susquehanna 2	-Residual Heat Removal	-Tubes, Pipes and Ducts	April 1985
17.	Bruce 8	-Condensate and Feedwater	-Displacement of the Deaerator	April 1987

4.4 Summary of Reported Thermohydraulic Conditions

The authors of the incident reviews references in Sections 4.1-4.3 did not report the thermalhydraulic conditions under which the waterhammer occurred. Presumably, this was because there are no specific models for analyzing the underlying causes. The systems which experienced the waterhammer give an indication of the general thermalhydraulic conditions. It should be noted that both low and high pressure systems were involved.

The following is a brief summary of thermalhydraulic conditions that were reported. In addition, the discussion of experimental studies in Section 6 reports thermalhydraulic conditions.

4.4.1 Indian Point 2

Westinghouse carried out tests at Indian Point 2 after waterhammer occurred in the feedwater line (Nov. 1973). It is believed that waterhammer was caused by slug formation because steam flowed into the feedline after the feedring was uncovered. They were able to produce waterhammer in the tests and measured a temperature excursion of about 350 °F (177 °C) in the feedline indicating sudden condensation took place at a pressure of 135 psia (931 kPa) generating a pressure change of 850 psi (5.86 MPa). The test results indicated the rate of auxiliary feedwater flow was an important parameter in the initiation of waterhammer.

4.4.2 Browns Ferry 1

At Browns Ferry Unit 1 there was waterhammer damage to high pressure core injection turbine steam supply piping (April 1984). In Reference 2 the initiating event was identified as the acceleration of a water slug because of condensation of 150 psi (1.03 MPa) steam being used to charge the line.

4.4.3 San Onofre 1

In November 1985 there was a severe waterhammer incident in the feedwater piping at the San Onofre 1 station [Ref.10]. In this incident the feedwater lines were accidentally drained and filled with steam. Waterhammer occurred when auxiliary feedwater (less than 100 °F (38 °C)) entered the lines.

The feedwater flow rate was varied between 155 gpm (9.78 L/S) and 40 gpm (2.5 L/S). The waterhammer occurred when the feedwater pipe was refilling at the lower flow rate.

4.4.4 Shearon Harris Plant

Early in the operation of the Shearon Harris plant, waterhammer was caused in the Component Cooling Water (CCW) system by a steam bubble collapse [Ref.11]. The CCW system is the heat sink for the residual heat removal system which was being placed in service. The CCW coolant in the heat exchanger was heated to 117°C as the flow was stopped to slow the cooldown rate. It was near saturation at the CCW pump discharge pressure and flashed when the outlet valve was opened. The subsequent collapse of the steam bubble caused waterhammer. There was no damage.

4.4.5 LOFT Reactor

Waterhammer incidents have been observed in the secondary cooling system of the LOFT Reactor [Ref.12]. Reactor heat is dissipated to atmosphere via a horizontal air cooled condenser which operates at 2 MPa and 210 °C.

Waterhammer has been observed following a scram which leads to flashing in the condensate receiver tank returning steam to the condenser. The countercurrent flow of steam and condensate causes the waterhammer. Waterhammer was observed with the condenser operating at 1.4 MPa and at reduced intensity when the pressure was increased to 2 MPa.

4.4.6 Kanupp PK-1

Waterhammer was observed in steam lines leading to a cracked elbow in a steam drain water line. When the incident occurred the primary system temperature was 414 °F (212 °C) and the steam pressure 325 psig (2.24 MPa(g)).

5. POSTULATED WATERHAMMER MECHANISMS

Following the incident at Indian Point 2 in 1973, Westinghouse postulated a slug formation and steam condensation mechanism to explain the steam generator waterhammer [Ref.2]. Their model is the accepted but not proven underlying mechanism. It is supported by the fact that the associated design fixes appear to have eliminated the potential for waterhammer [Ref.4].

The severe waterhammer incident in the feedwater lines at San Onofre Unit 1 in 1985 is postulated to be due to the same underlying mechanism as steam generator waterhammer [Ref.10]. In both cases stratified steam-water flow leads to slug formation and steam bubble collapse.

The postulated models for slug formation are reviewed in detail here for two reasons:

(1) the models illustrate the mechanism for generating severe pressure transients as the result of mixing steam and cold water

(2) The design configurations illustrate the importance of mechanical parameters in determining the conditions for waterhammer.

5.1 Steam Generator Waterhammer

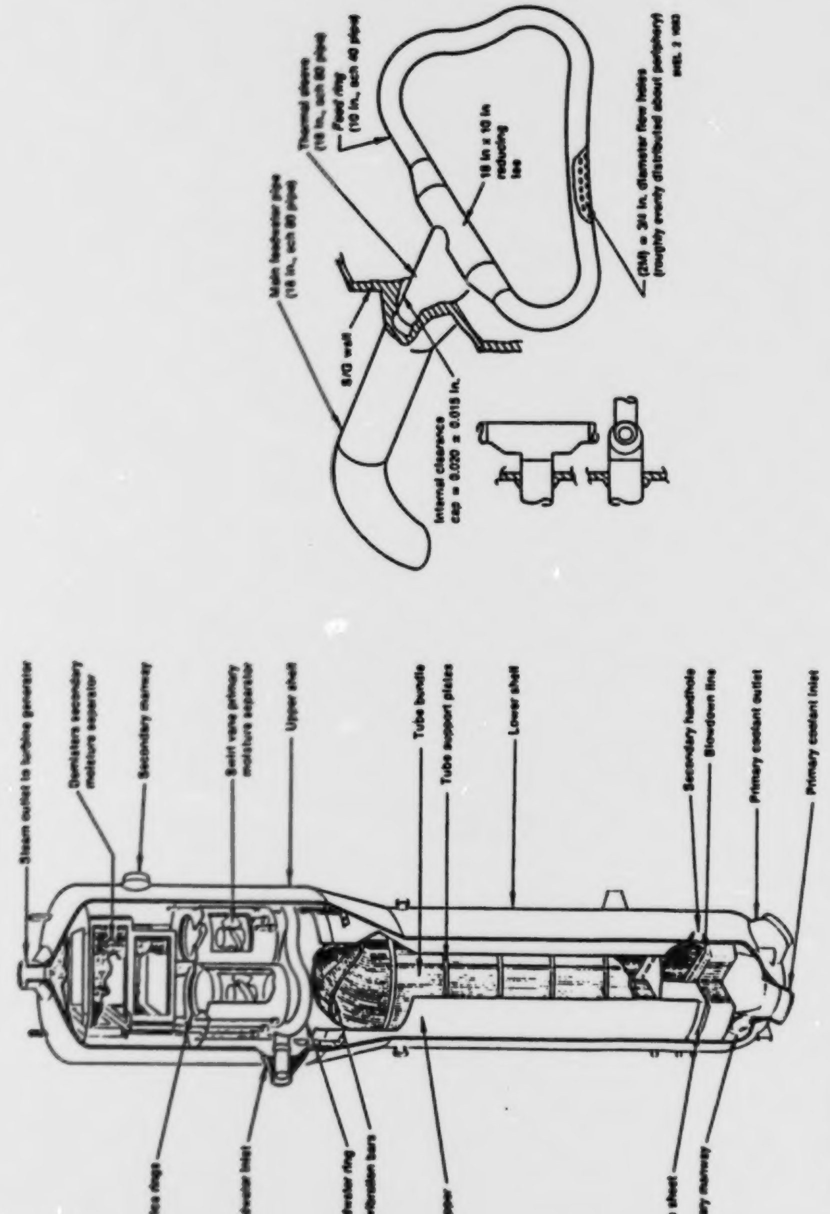
Steam generator waterhammer is defined as waterhammer induced by steam condensation in the feedwater line at its connection to the steam generator. Hans and Anderson [Ref.13] have reviewed the prevention and mitigation of steam generator waterhammer events. Their approach is followed here.

A steam generator of the type that experienced waterhammer at Indian Point 2 is shown in Figure 5. The feedwater inlet is above the tube bundle and water enters the steam generator from holes in the bottom of the feedring. Thus during transients when there is an interruption of feedwater flow the steam generator level can drop below the feedring so that it drains.

For rapid transients the feedwater line will fill with steam before feedwater flow is restored. When the flow is restored a slug is formed as shown in Figure 6 and accelerated by the collapse of the steam bubble.

The forces accelerating the water slug is the difference between the steam generator pressure (> 6.9 MPa) and the pressure in the condensing steam bubble. The size of the steam bubble determines the momentum of the slug when it impacts on the water column. Thus, the size of the resultant pressure pulse is determined by

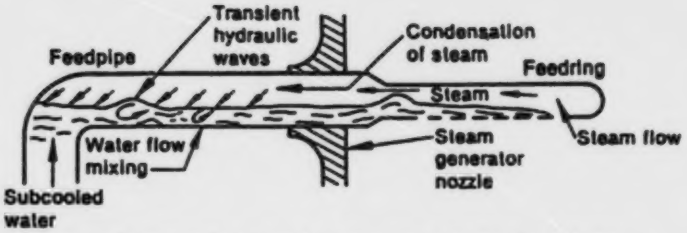
- steam bubble condensation rate
- volumes of the steam bubble and slug
- steam generator pressure
- speed of sound in the feedwater line
- piping geometry


Steam outlet to turbine generator
Demisters secondary moisture separator
Secondary manway
Swirl vane primary moisture separator
Upper shell
Tube bundle
Tube support plates
Lower shell
Secondary handhole
Blowdown line
Primary coolant outlet
Primary coolant inlet
Orifice rings
Feedwater inlet
Feedwater ring
Antivibration bars
Wrapper
Tube sheet
Primary manway
Main feedwater pipe (16 in., sch 80 pipe)
Thermal sleeve (16 in., sch 80 pipe)
Feed ring (10 in., sch 40 pipe)
S/G wall
18 in x 10 in reducing tee
Internal clearance cap = 0.020 ± 0.015 in.
(2N) = 3/4 in. diameter flow holes (roughly evenly distributed about periphery)

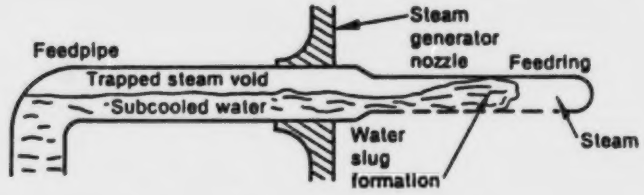
2a. Typical Westinghouse feedring steam generator

2b. Sketch of "unmodified" Westinghouse feedring

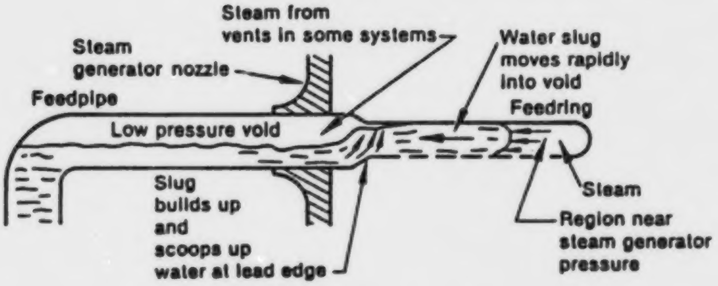
Figure 5. A Westinghouse Steam Generator Showing the 'Unmodified' Feedring (from Reference 13)



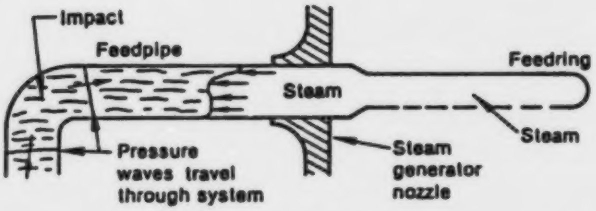
(a) Possible Steam-Water Mixing Phenomena in the Feed System



(b) Possible Trapping of a Steam Void



(c) Possible Slug Acceleration into Void



(d) Possible Water Slug Impact

INEL 2 1076

Figure 6. Postulated Sequence of Events Leading to Steam Generator Waterhammer (from Reference 13)

In severe cases the pressure can be several times that of the steam generator.

This model of steam generator waterhammer was used as the basis for the recommended design changes shown in Figures 7 and 8. The feedring is modified by replacing the bottom holes with short J-tubes. the purpose of this change is to slow the draining of the feedring. By minimizing the horizontal length of feedwater pipe at the nozzle the volume of feedwater line that can be voided is minimized. Figure 8 shows several alternative arrangements assuming the feedwater nozzle is the highest point in the line.

5.2 Feedwater System Waterhammer

The severe waterhammer incident at San Onofre Unit 1 in November, 1985 is believed to have been steam condensation induced [Ref.10]. That is, the same physical mechanism as postulated for steam generator waterhammer.

A complex sequence of events lead to the waterhammer incident starting with a unit trip. In brief, because of a failure of check valves, steam was able to blow back through the feedwater lines from each steam generator. The operators isolated the feedwater lines and the voided lines were refilled with cold (< 38 °C) auxiliary feedwater. Waterhammer occurred in one loop during the refilling of the voided lines. There was severe damage to the feedwater piping, pipe supports and valves.

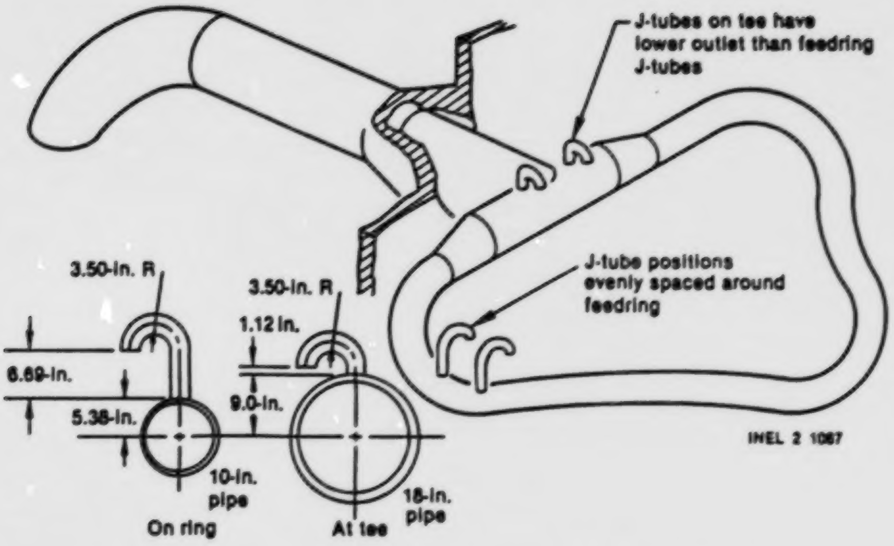
The postulated cause of the waterhammer is illustrated in Figure 9. The inflow of cold feedwater condenses steam void generating further inflow of steam. As the pipe fills a counterflow of steam and feedwater exists. Instabilities develop at a critical depth of water so that surface waves bridge the pipe trapping steam voids with water slugs. Condensation of the trapped steam bubbles leaves an unbalanced force across the slug which accelerates it towards tha collapsing void. The impact of the slug on the water column generates a pressure wave which propagates through the system.

The steam condensation mechanism can generate severe waterhammer because of the large forces for accelerating the water slug. In the San Onofre incident the accelerating force is estimated to be 4.8 MPa [Ref.10].

Based on the slug formation model, it is believed that the conditions conducive to condensation induced waterhammer are:

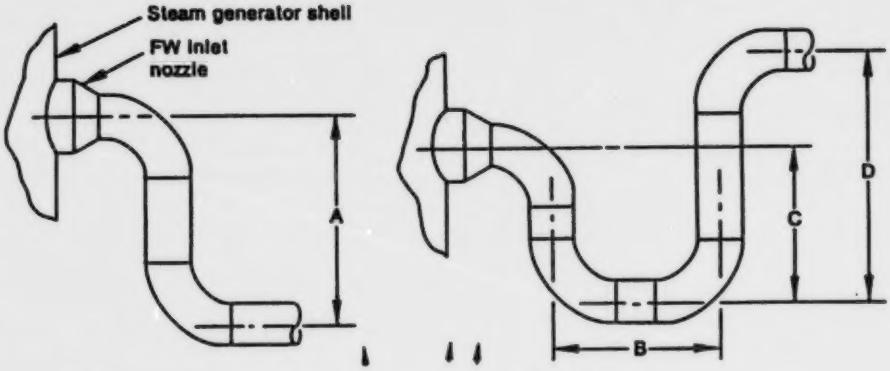
- sufficient steam to act as a reservoir
- a long horizontal run of voided pipe
- cold water filling of the voided pipe at a rate that generates surface waves and slug formation.

Analysis of this model is discussed further in Section 6.


J-tubes on tee have lower outlet than feedring J-tubes
J-tube positions evenly spaced around feedring
3.50-in. R
3.50-in. R
1.12 in.
6.69-in.
5.38-in.
9.0-in.
10-in. pipe
On ring
18-in. pipe
At tee
INEL 2 1067

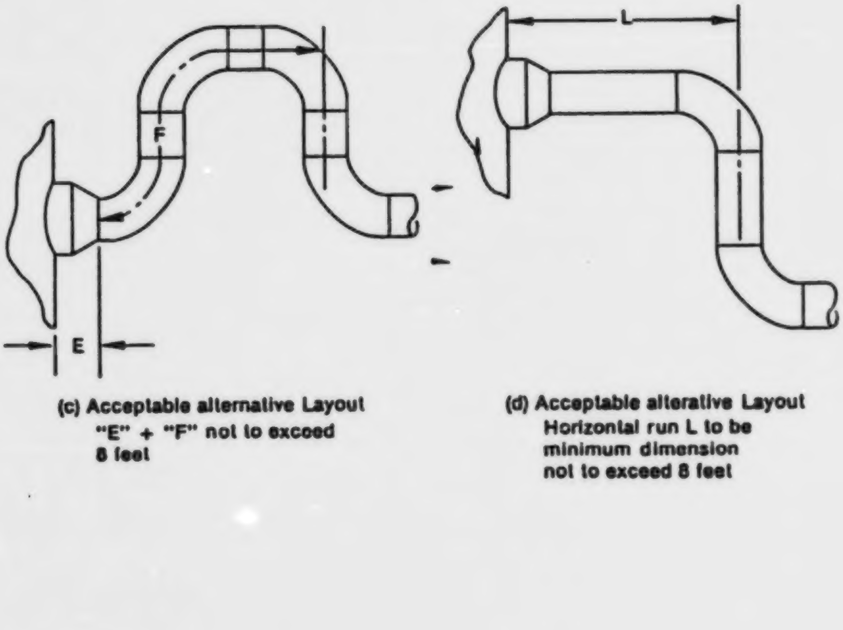
. Westinghouse J tube feedring configuration at Indian Point 2

Figure 7. Modified Feedring Design to Reduce Steam Generator Waterhammer (from Reference 13)



(a) Preferred Layout
"A" - to be not less
than 24 inches

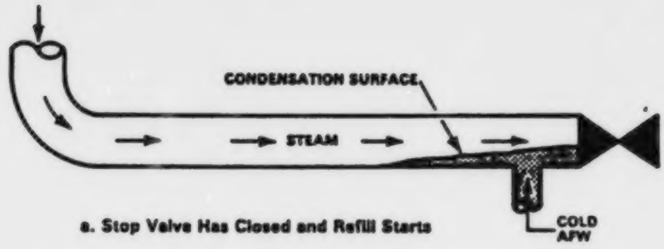
(b) Second Best Layout
"C" - to be not less than 36 inches
"B" & "D" no requirement established



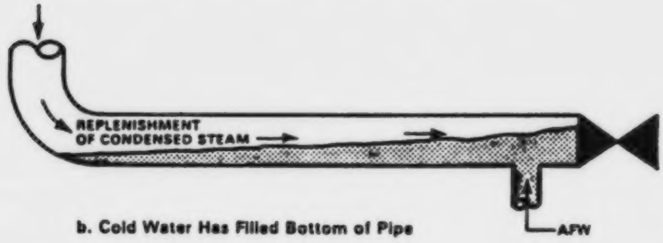
(c) Acceptable alternative Layout
"E" + "F" not to exceed
8 feet

(d) Acceptable alterative Layout
Horizontal run L to be
minimum dimension
not to exceed 8 feet

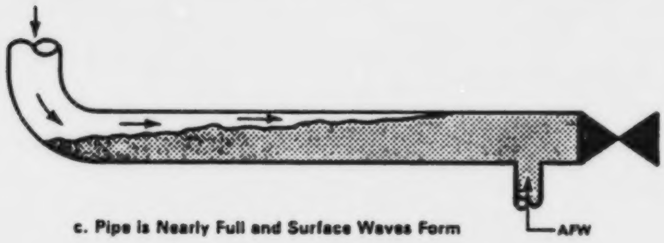
Figure 8. Alternative Feedwater Piping Designs to Minimize Steam Generator Waterhammer (from Reference 13)



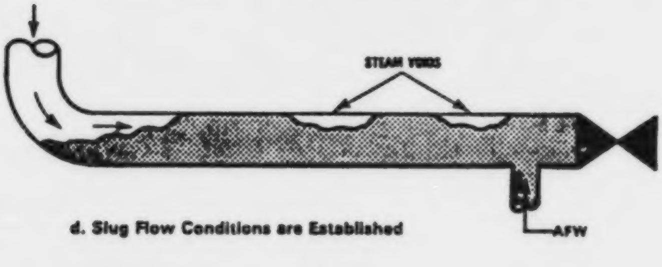
a. Stop Valve Has Closed and Refill Starts



b. Cold Water Has Filled Bottom of Pipe



c. Pipe is Nearly Full and Surface Waves Form



d. Slug Flow Conditions are Established

Figure 9. Filling of a Voided Feedwater Line Causing Waterhammer (from Reference 10)

6. WATERHAMMER EXPERIMENTS AND MODELS

There have been a few experiments designed to develop an understanding of the physics of condensation induced waterhammer [Ref.14-17]. Also, Akagawa and Fujii [Ref.8] have studied the propagation of pressure waves in two-phase flow. Scholl [Ref.18] has studied experimentally the closure of feedwater line check valves in response to a pipe rupture which can generate waterhammer without condensation.

There have been several analytical and phenomenological models developed for two-phase waterhammer phenomena [Ref.19-25]. None of the models has the sophistication required to predict the details of condensation induced waterhammer. Nevertheless they provide insight into the underlying mechanisms and correlate some of the critical parameters. The following sections present some of the models used to correlate experimental data and to predict waterhammer in nuclear systems.

6.1 Steam Generator Waterhammer Correlation

Vreeland [Ref.23] has developed a correlation for the pressure surge experienced in steam generator waterhammer. The maximum pressure is given by

$$\Delta P = (a\rho V_s \beta / 9\pi g D^2)\ \sigma \quad \text{(psia)} \qquad (6\text{-}1)$$

where a = sound velocity

ρ = water density

D = pipe diameter

V_s = specific volume of steam

g = acceleration of gravity

β = ratio of steam volume to volume of the pipe

σ = rate of steam condensation

Vreeland notes that condensation rates in excess of 200 lbm/sec (91 kg/s) are necessary to produce observable inertial effects in 12 in (0.3 m) and 18 in (0.46 m) pipes at operating pressures and temperatures.

In Equation 6-1 the parameter β correlates the piping geometry and steam bubble size. The impact pressure of the water slug depends upon the distance through which it is accelerated. That is the length of the void when rapid condensation occurs. The correlation between impact pressure and initial void length is shown in Figure 10 [Ref.25].

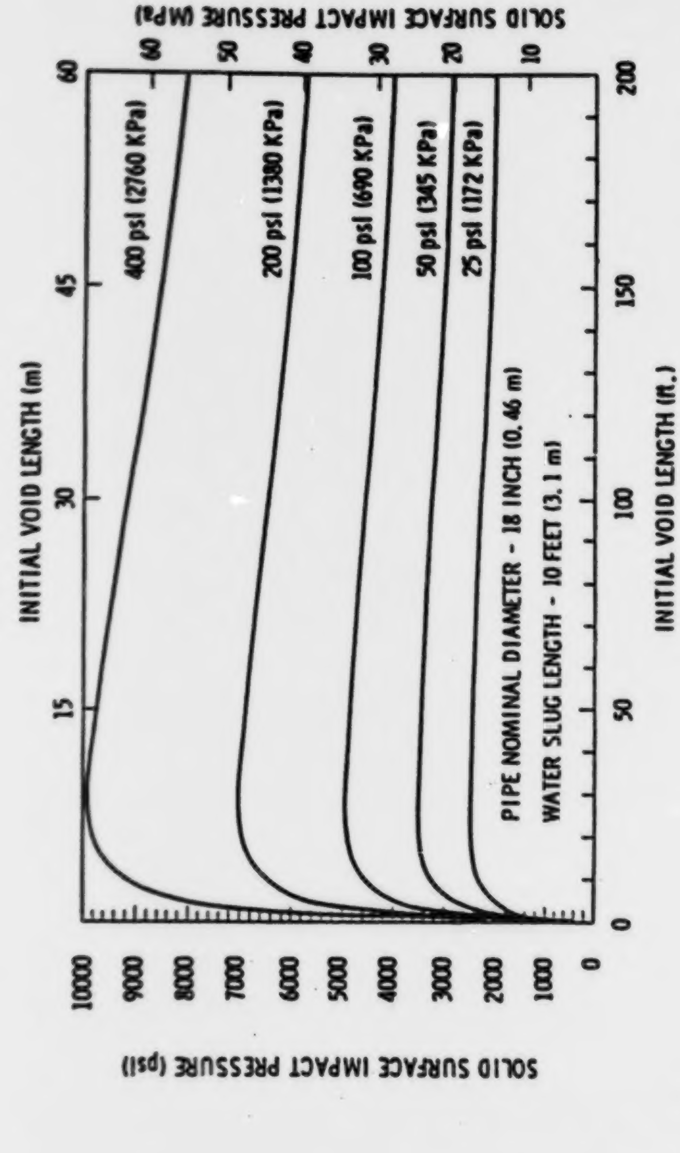


Figure 10. Slug Impact Pressure as a Function of Driving Head and Void Length (from Reference 25)

It is important to note that Equation 6-1 cannot be used to predict the incidence of waterhammer. To do that requires a model for β and σ which contains the geometry and thermalhydraulic conditions. Nevertheless it is a useful correlation of the physical parameters involved.

6.2 Feedwater Line Waterhammer

Chiu et al. [Ref.24] have performed a one-dimensional heat transfer analysis of the San Onofre waterhammer incident. In their analysis two parameters were found to be very important in controlling the initiation of waterhammer. The parameters are the horizontal length of the feedwater pipe and the feedwater flow rate. Figure 9 illustrates the San Onofre model.

The results of the analysis are shown in Figure 11 where the initiation of waterhammer is correlated with the auxiliary feedwater flow rate and the horizontal length of the feedwater pipe. It should be noted that waterhammer is predicted for Loop B as it occurred while Loops A and C are correctly predicted to not experience waterhammer.

The upper and lower limits in Figure 11 can be understood as follows. The steam inflow rate has to be large enough to create a slug from surface waves. At high feedwater flow rates the condensing steam volume is filled by feedwater rather than steam. Thus, there is not sufficient steam inflow. For very low feedwater flow rates the feedwater is heated to a depth that will not allow rapid condensation of a steam bubble if a slug does form.

It should be noted that a dependence upon feedwater flow rate was observed in tests at Indian Point 2 [Ref.2]. This supports the model of Chiu et al., since the underlying mechanisms are essentially the same in the two cases.

6.3 Waterhammer During ECC Injection

The injection of Emergency Core Cooling (ECC) water following a LOCA creates conditions that could give rise to rapid condensation and waterhammer. Jackobek and Griffith have studied [Ref.17] the potential for waterhammer in the event of a small break LOCA. They conducted experiments with a laboratory system shown in Figure 12.

ECC injection into the cold legs gives rise to stratified steam-water flow in the horizontal cold leg sections. This is similar to the situation for steam generator and feedwater system waterhammer. The underlying mechanism is illustrated in Figure 13. In this case the steam flow is in the same direction as the cold water flow.

Waterhammer was observed in the tests. Figure 14 shows test results for different system pressures. The system pressure is very low relative to nuclear system pressure.

Jackobek and Griffith have analyzed their data assuming slug formation occurs when a critical depth is reached in the cold leg. At this critical depth the steam flow generates bridges between the water surface and the pipe wall. This occurs when the Taitel-Dukler number is unity.

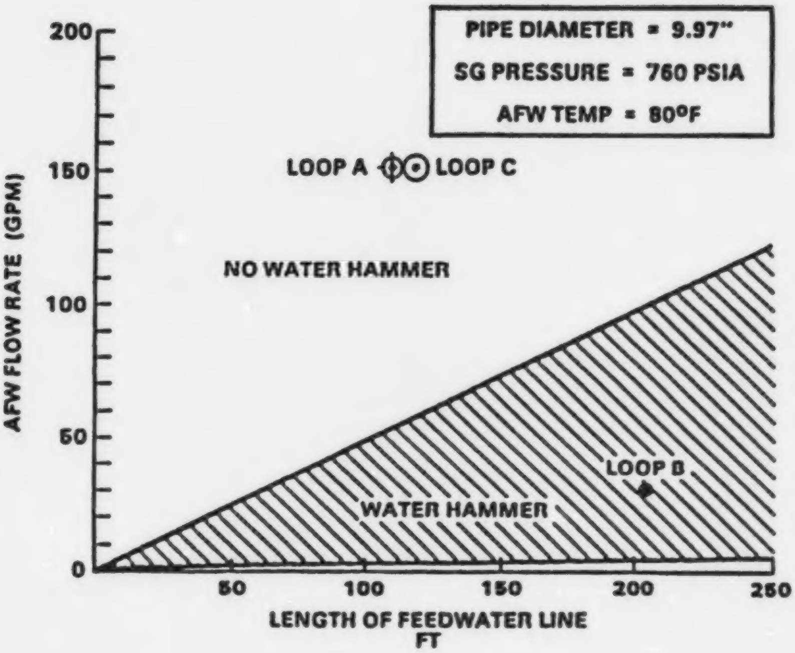


Figure 11. Correlation of Waterhammer Initiation with Feedwater Flow and Pipe Length (from Reference 24)

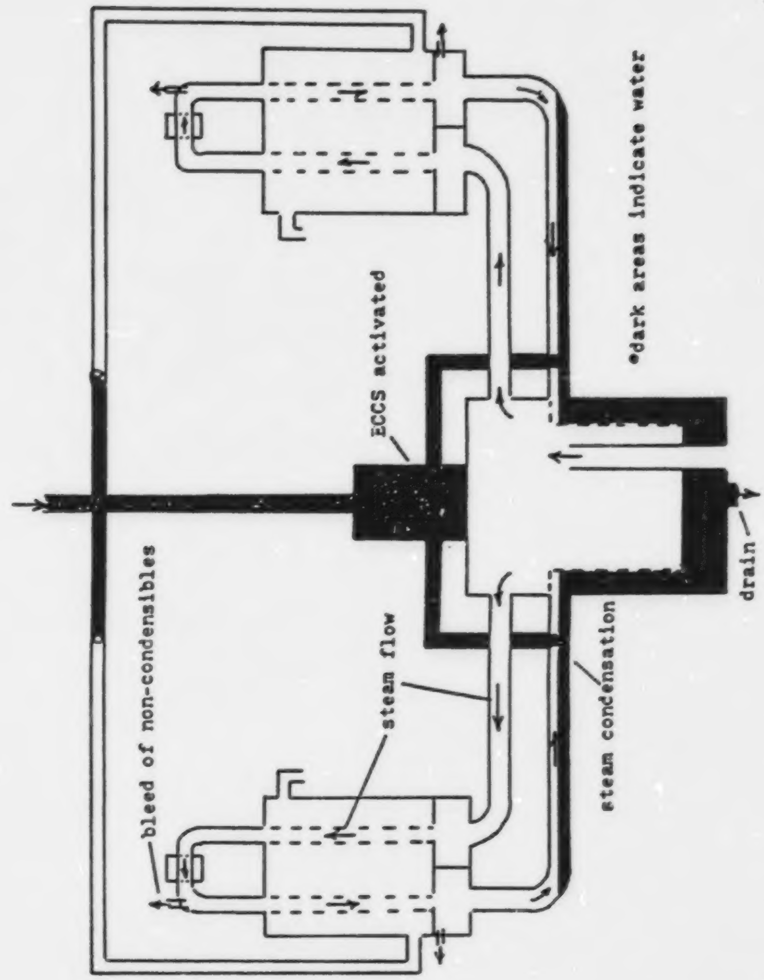


Figure 12. Experimental Layout to Study Cold-Leg Waterhammer (Reference 17)

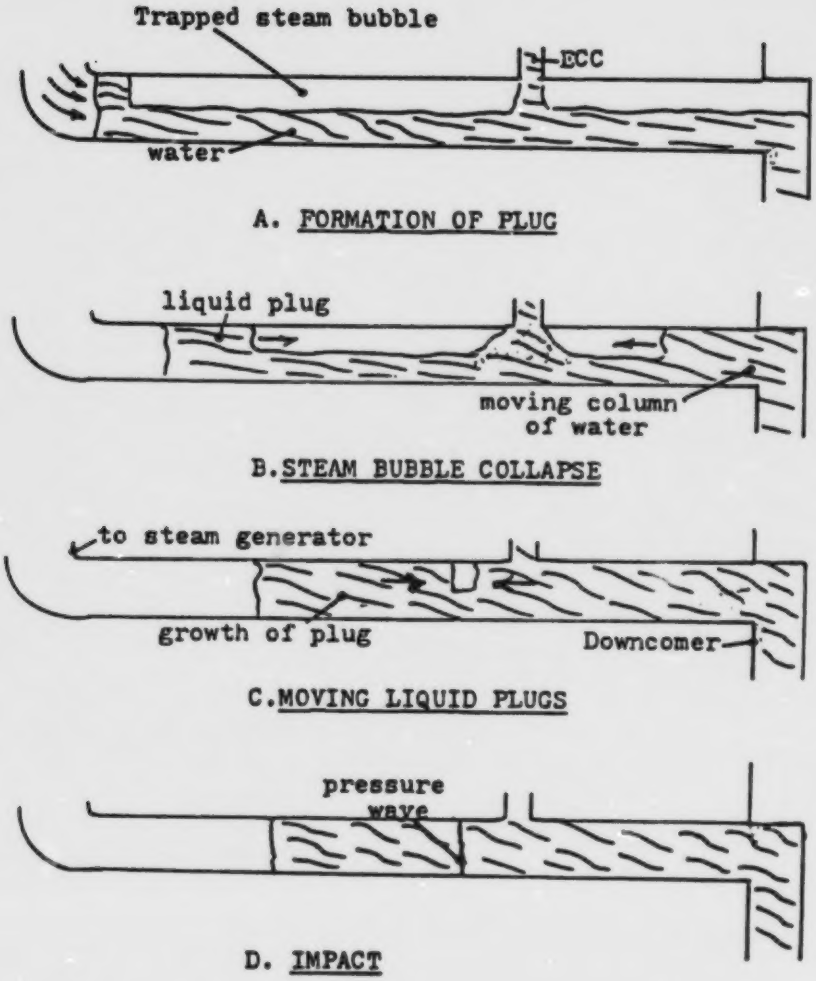


Figure 13. Steam Bubble Collapse Waterhammer Process in Experimental Flow Model During ECC (from Reference 17)

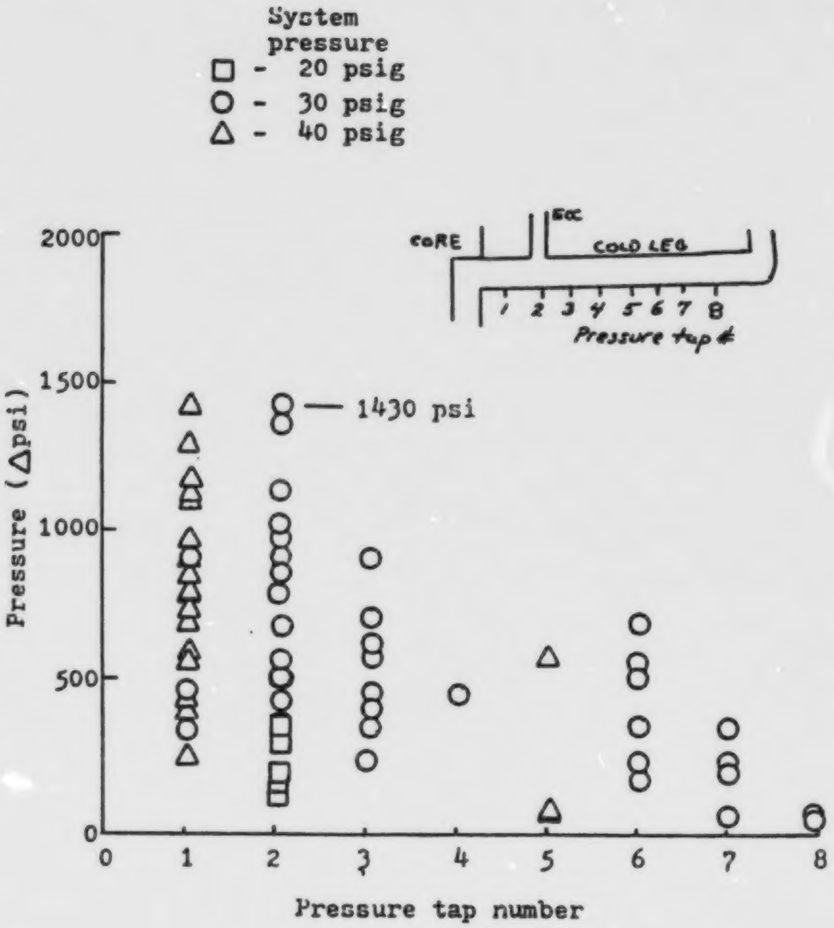


Figure 14. Measured Waterhammer Pressures During ECC Tests (from Reference 17)

The Taitel-Dukler number is

$$N_{TD} = (1-\alpha)\ \rho_S\ V_S^{\ 2}\ Fr/\alpha\rho_\ell V_\ell^{\ 2}\ (1-YD_o)^2 \qquad (6\text{-}2)$$

$$Y = 3/2\ Y_c \qquad (6\text{-}3)$$

$$Y_c = 0.325\ (Q/D_o)^{2/3} + 0.083\ D_o \qquad (6\text{-}4)$$

where Y_c = critical depth

Y = liquid depth

Fr = Froude Number

V_S = steam velocity

V_ℓ = liquid velocity

ρ_S = steam velocity

ρ_ℓ = liquid density

α = void fraction

D_o = pipe diameter

Q = volumetric flow rate

As the steam bubble collapses the water slug and water column are accelerated towards each other. Their momentum can be calculated by solving the dynamic equations. A conservative estimate of the resultant peak pressure upon impact is then

$$\Delta P = a\rho_\ell\ (V_1 + V_2)/g \qquad (6\text{-}5)$$

where V_1, V_2 = plug and water column velocities

a = sound speed

g = acceleration of gravity

The model overpredicts the measured pressures by a factor of 2 if the water column is assumed stationary and a factor of 3 if it is assumed to accelerate. The authors note that predictions are conservative because they assume instantaneous condensation, and non-condensibles in their steam would reduce the sound speed. They also note difficulties in correlating the location of the predicted peak pressure with the pressure sensors.

Jackobek and Griffith have extrapolated their model to the operating conditions of a PWR plant. Their model predicts bounds for the onset of potential waterhammer in terms of the fluid mechanical characteristics of the ECC system. Figure 15 shows a predicted stability bound as a function of system pressure and ECC flowrate for free 'overfall' of coolant into the core. The high pressure safety injection pump characteristic for a typical PWR plant is superimposed in the Figure. In this particular case the model predicts stability against waterhammer because the pump is too small to deliver the critical injection flowrate.

If there is not a free 'overfall' of cold water into the core, the cold leg will fill. Jackobek and Griffith's experiments show that at particular depth of water in the cold leg waterhammer will occur due to slug formation. In this case the bound for onset of waterhammer is predicted as a function of cold leg water depth and system pressure as shown in Figure 16.

The forcing function is different for waterhammer occuring when there is a free 'overfall' and when the cold leg is filling. In the filling case waterhammer will always occur but only for the time required to fill the pipe above the critical depth.

Equation 6-5 gives the predicted peak impact pressure as a function of the water slug velocity at impact. For a given system pressure the maximum impact velocity increases as a function of the time the slug is accelerated. In practice friction losses and mass accumulation limit the maximum velocity. Figure 17 shows Jackobek and Griffith's prediction of the limiting impact velocity as a function of system pressure and slug length. The maximum velocity then bounds the impact pressure through Equation 6-5.

Jackobek and Griffith have predicted the peak waterhammer pressures resulting from steam bubble collapse during ECC in a PWR. Their predictions are shown in Figure 18 as a function of system pressure. They show results for loop seal remaining stationary and being accelerated towards the slug that creates the steam bubble. The peak pressures are in the range 10-100 MPa.

6.4 Steam Bubble Collapse Waterhammer

Attia and Ruhl [Ref.21] and Lahey and Drew [Ref.22] have developed analytical models for waterhammer in the case of a pipe containing steam between a closed end and a cold pool of water. They have found analytical solutions for the impact velocity when the water column strikes the closed end of the pipe. Although the maximum velocities are bounds, these models have limited application to waterhammer conditions in an operating plant.

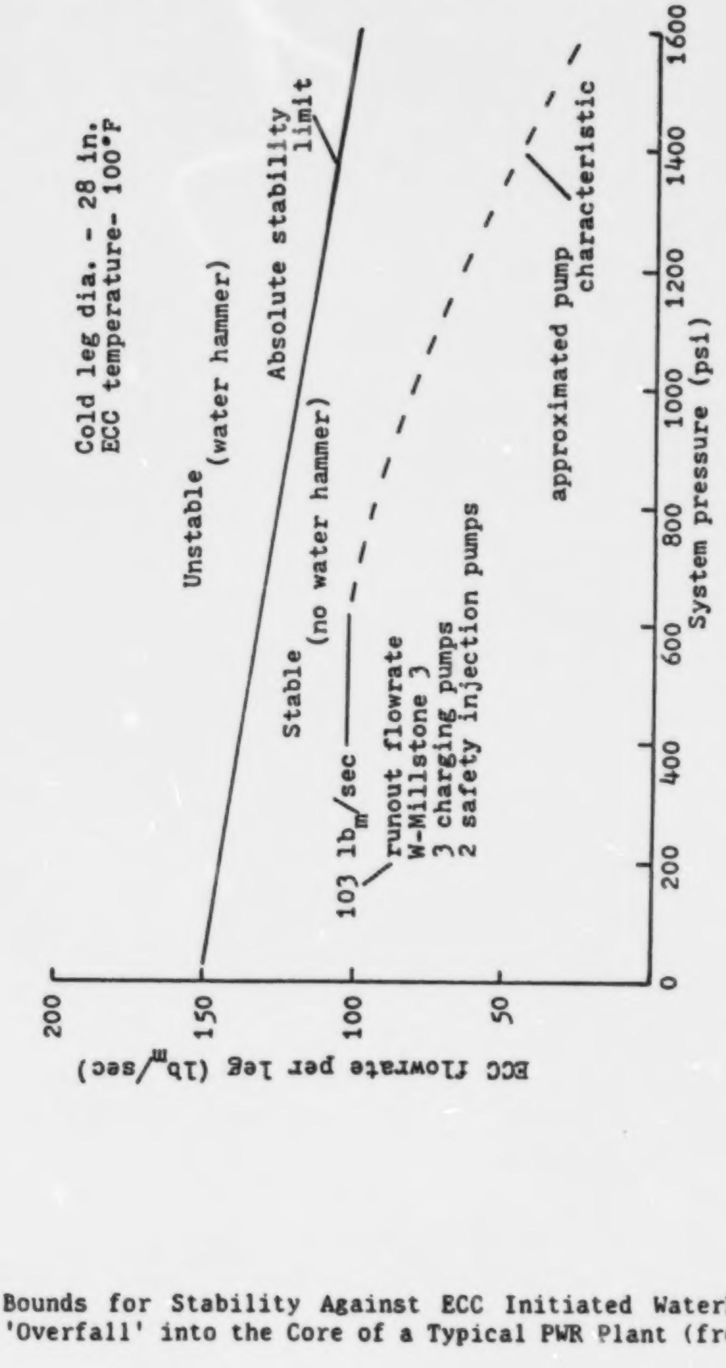


Figure 15. Bounds for Stability Against ECC Initiated Waterhammer for Free 'Overfall' into the Core of a Typical PWR Plant (from Reference 17)

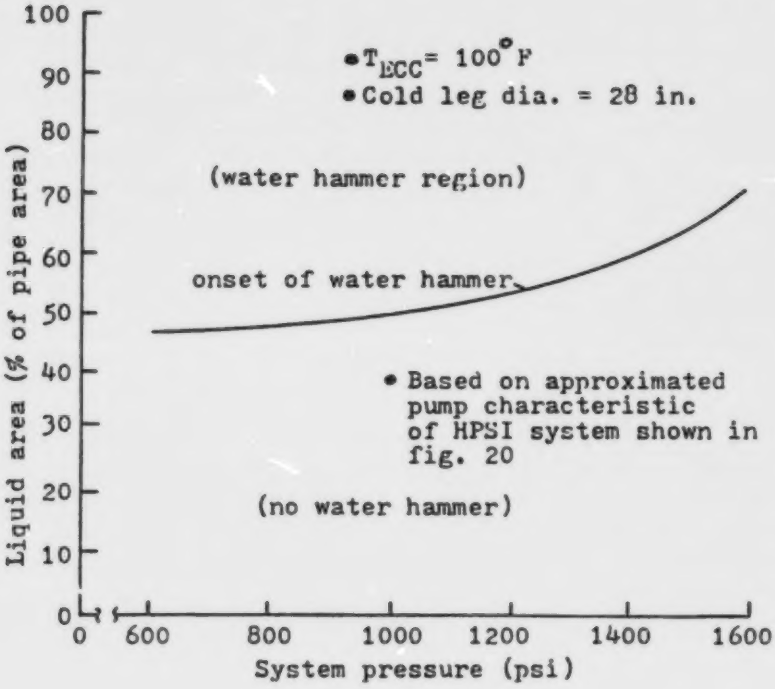


Figure 16. Bounds for Stability Against ECC Initiated Waterhammer as a Function of Water Depth in the Cold Leg of a Typical PWR Plant (from Reference 17)

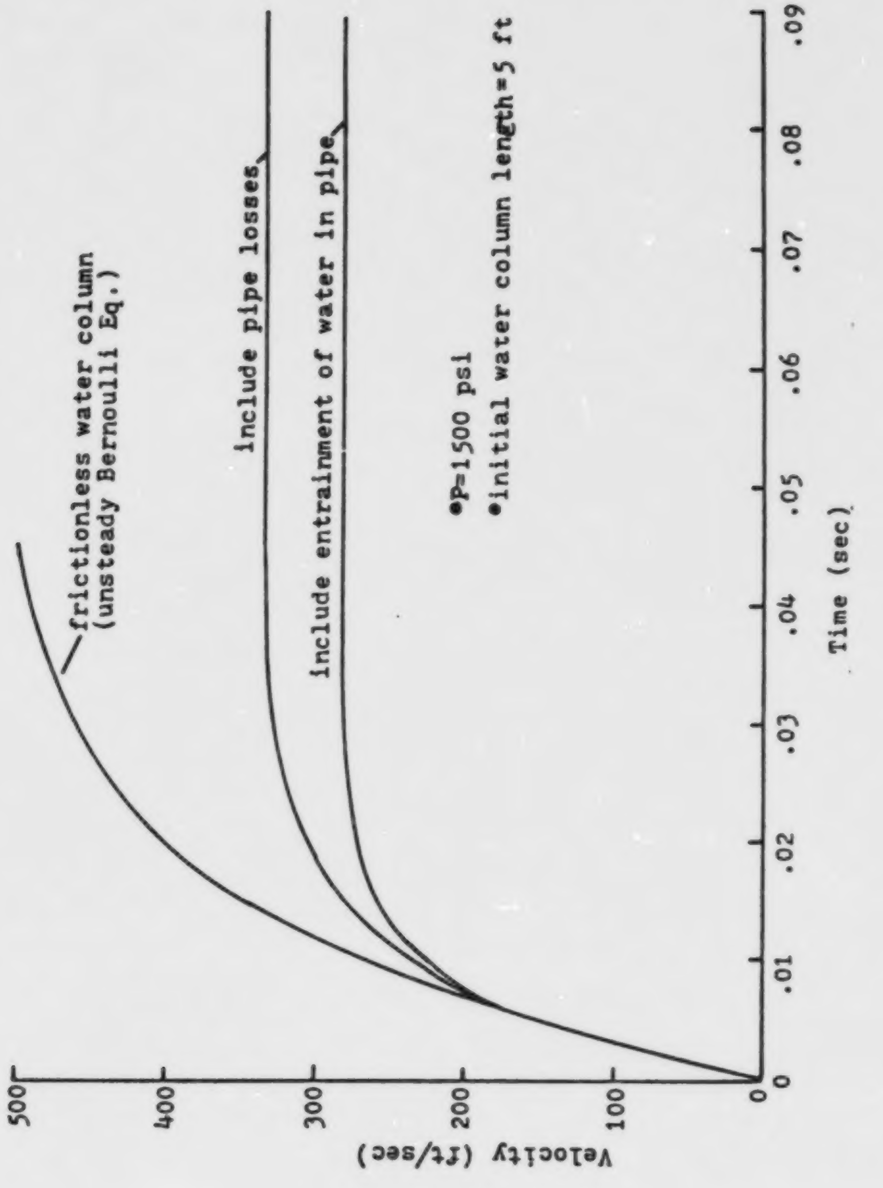


Figure 17. Effect of Geometrical Pressure Losses and Plug Growth on Maximum Obtainable Velocity During Steam Bubble Collapse (from Reference 17)

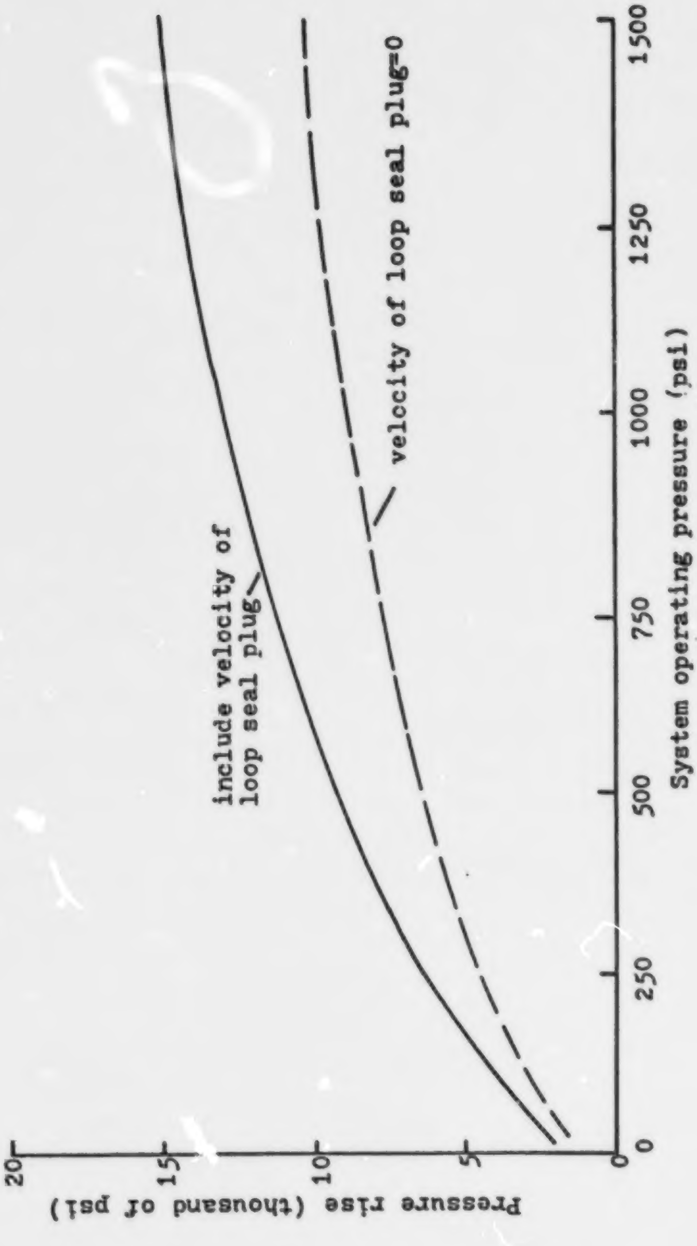


Figure 18. Calculated Waterhammer Pressures as a Result of Steam Bubble Collapse During ECC in a PWR (from Reference 17)

7. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

7.1 Summary and Conclusions

A literature survey was undertaken to determine the available literature on dynamic transients caused by injecting cold water into a steam-water mixture. Nearly all the literature is focused on waterhammer in nuclear power plants. Nuclear plants are emphasized because the USNRC designated waterhammer an Unresolved Safety Issue over the period 1978-1984.

Most of the data on waterhammer incidents is from U.S. experience. However, the NEA database includes some incidents from outside the U.S. (Canada, Europe and Asia). The data are summarized to present information according to the following:

- systems involved
- underlying causes
- damage assessment
- bounds for the peak pressures

Classical waterhammer can occur under any thermalhydraulic conditions although it will be more severe in water filled systems. There is a potential for condensation induced waterhammer whenever there is a steam supply contacting a supply of cold water. Thus, one would expect waterhammer incidents to be reported for a wide variety of systems and conditions, which is the case. Some systems are more prone to waterhammer because of specific design features. An example is the steam generator waterhammer where the feedwater enters at the top via a feedring. Preheat steam generators in which feedwater enters at the bottom do not experience waterhammer in the same way [Ref.27].

The underlying causes of reported waterhammer events that are directly related to cold water injection into two-phase mixtures are:

- steam bubble collapse

- slug formation from the mixing of steam and water from interconnected systems.

The waterhammer associated with steam generators and feedwater lines are specific examples. In these cases, cold feedwater is rapidly condensing steam from the steam generators.

Condensation induced waterhammer can generate large pressure waves which propagate through the system. The pressure wave can cause severe damage including pipe fracture, failure of pipe supports and restraints as well as damage to valves and fittings. The incident report summaries in Section 4 include the range of damage to systems.

There have been a few analyses of steam bubble collapse and slug formation. The authors have presented bounds for the onset of waterhammer in terms of system parameters. These parameters include cold water injection rate, pipe length and water depth as shown in Figures 11, 15, and 16. For given system conditions there are limits to the slug velocity, and hence impact pressure, as shown in Figure 17.

It is important to note from the limited work done that the bounds for onset of waterhammer and peak pressures are system dependent. That is, they depend upon thermodynamic conditions and mechanical parameters such as flow rate and pipe size. The system dependence of the bounds means that each reactor type and station design must be reviewed for susceptibility to condensation induced waterhammer.

Two-phase waterhammer is a complex physical process. There is no developed methodology for analyzing and predicting the onset of condensation induced waterhammer. Kim [Ref.25] has presented an overview of the research requirements to establish a technical basis for the prevention, mitigation and accommodation of waterhammer. The following areas would be considered:

(i) Condensation phenomena in mixed steam-water flows.

(ii) Waterhammer forcing functions for evaluating the structural response.

(iii) A scaling analysis for extrapolating laboratory results to operating conditions.

(iv) A general analytical methodology for predicting the consequences given initial thermalhydraulic conditions.

(v) An operational map for designers and operators in the form of graphs and tables showing regions of potential waterhammer.

(vi) A database for validating the analytical methodology and operational map.

EPRI has undertaken a major R & D project [Ref.28] encompassing the scope outlined by Kim. Their program is proprietary and the results will not be published in the open literature. Therefore, the EPRI program has not been reviewed for this report.

From this study we also conclude that there is not a sufficient database of theoretical and experimental results to predict the consequences of cold water being injected into a two-phase mixture. The correlations reported in Section 6 provide insight into critical parameters controlling the onset of waterhammer. In particular, they show that mechanical parameters are as important as thermalhydraulic conditions in determining bounds for stability of the system against waterhammer. The models can be used for conservative estimates of potential peak pressures in particular cases of stratified steam and cold water flows.

The analytical models described in Section 6 can only be applied to specific physical systems where stratified steam and cold water flows are postulated to exist. There are no models for addressing the general phenomenon of mixing cold water with a hot two-phase mixture. As a result, general analytical methods have yet to be developed for predicting forcing functions so that the dynamic response of a system can be studied. The development of such methods is one of the objectives of the EPRI study [Ref.28].

Gruel, et al [Ref.16] have conducted theoretical and experimental studies of waterhammer and the propagation of pressure waves in laboratory apparatus. There have been no tests, or test methods developed, for examining the dynamic response due to specific physical characteristics of a system.

7.2 Recommendations

1. Since EPRI has undertaken a major R & D program on condensation induced waterhammer, the scope of their program should be considered before independent studies are undertaken. Specific studies directed to an assessment of the CANDU design should be undertaken where they are needed to extend the EPRI program for BWR and PWR designs. The identification of any unique CANDU design features that create a potential for severe waterhammer would be of immediate interest.

2. The formation of slugs in stratified steam/water flows can lead to severe waterhammer. The necessary conditions for slug formation then become important criteria for predicting the occurrence of waterhammer. It is important to have a better understanding of these flow instabilities. This would include the dependence on pipe size and geometry. Subject to Recommendation 1, criteria should be developed for slug formation in steam/water flow mixtures.

3. Condensation is the driving mechanism for two-phase waterhammer. Subject to Recommendation 1, correlations should be developed for condensation rates as a function of thermodynamic conditions and geometry.

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9. BIBLIOGRAPHY

A bibliography of the literature on waterhammer as obtained form the CAN/OLE search (Section 3) is appended in this section. The papers and reports have been grouped under the headings of responsible agencies. The groupings are as follows:

- United States Nuclear Regulatory Commission (USNRC)
- American Nuclear Society (ANS)
- Electric Power Research Institute(EPRI)
- American Society of Mechanical Engineers (ASME)
- Micellaneous (Universities, journals, etc.)

9.1 UNITED STATES NUCLEAR REGULATORY COMMISSION

1. TI - PIPE DAMPING RESULTS OF VIBRATION TESTS IN THE 33 TO 100 HERTZ FREQUENCY RANGE.
   AU - WARE, A.G.
   PU - JUL 86; 52P; SPONSORED BY NUCLEAR REGULATORY COMMISSION, WASHINGTON, DC. OFFICE OF NUCLEAR REGULATORY RESEARCH, AND DEPARTMENT OF ENERGY, WASHINGTON, DC; PC A04/MF A01
   AB - RESEARCH WAS PERFORMED TO DETERMINE BEST-ESTIMATE REPRESENTATION OF DAMPING VALUES FOR NUCLEAR PIPING SYSTEMS EXCITED IN THE 33 TO 100 HZ FREQUENCY RANGE. VIBRATIONS IN THE FREQUENCY RANGE ARE TYPICAL OF FLUID-INDUCED TRANSIENTS, FOR WHICH NO FORMAL PIPE DAMPING GUIDELINES EXIST. THE AVAILABLE DATA FOUND IN THE LITERATURE AND THE USNRC/INEL PIPE DAMPING DATA BANK WERE REVIEWED, AND TWO SERIES OF TESTS ON 3- AND 5-IN. LABORATORY PIPING SYSTEMS SUPPORTED WITH SEVERAL TYPICAL NUCLEAR PIPING SUPPORTS WERE CONDUCTED AS PART OF THE RESEARCH PROGRAM. IT WAS CONCLUDED THAT A SUITABLE REPRESENTATION OF THE TEST DATA CAN BE MADE BY EXTENDING THE PRESSURE VESSEL RESEARCH COMMITTEE (PVRC) UNINSULATED PIPING CURVE AT 3% OF CRITICAL DAMPING FOR FREQUENCIES > OR = 20 HZ.

2. TI - LOSS OF POWER AND WATER HAMMER EVENT AT SAN ONOFRE, UNIT 1, ON NOVEMBER 21, 1985
   CS - NUCLEAR REGULATORY COMMISSION, WASHINGTON, DC.; 044100000
   PU - JAN 86; 203P; TECHNICAL DEPT; PC A10/MF A01
   AB - ON NOVEMBER 21, 1985, SOUTHERN CALIFORNIA EDISON'S SAN ONOFRE NUCLEAR GENERATING STATION, UNIT 1, LOCATED SOUTH OF SAN CLEMENTE, CALIFORNIA, EXPERIENCED A PARTIAL LOSS OF INPLANT AC ELECTRICAL POWER WHILE THE PLANT WAS OPERATING AT 60 PERCENT POWER. FOLLOWING A MANUAL REACTOR TRIP, THE PLANT LOST ALL INPLANT AC POWER FOR 4 MINUTES AND EXPERIENCED A SEVERE INCIDENCE OF WATER HAMMER IN THE FEEDWATER SYSTEM WHICH CAUSED A LEAK, DAMAGED PLANT EQUIPMENT, AND CHALLENGED THE INTEGRITY OF THE PLANT'S HEAT SINK. THE MOST SIGNIFICANT ASPECT OF THE EVENT INVOLVED A NUMBER OF EQUIPMENT MALFUNCTIONS, OPERATOR ERRORS, AND PROCEDURAL DEFICIENCIES. THE REPORT DOCUMENTS THE FINDINGS AND CONCLUSIONS OF AN NRC INCIDENT INVESTIGATION TEAM.

3. TI - REPORT OF THE U.S. NUCLEAR REGULATORY COMMISSION PIPING REVIEW COMMITTEE. VOLUME 4. EVALUATION OF OTHER DYNAMIC LOADS AND LOAD COMBINATIONS.
   CS - NUCLEAR REGULATORY COMMISSION, WASHINGTON, D.C.
   PU - DEC 84; 383P; SEE ALSO NUREG-1061-V3; PC A17/MF A01
   AB - THIS REPORT DEALS WITH SIX TOPICAL AREAS: EVENT COMBINATIONS, RESPONSE COMBINATIONS, STRESS LIMITS AND DYNAMIC ALLOWABLES, WATER HAMMER LOADINGS, RELIEF VALVE OPENING AND CLOSING LOADS AND PIPING VIBRATION LOADS. FOREIGN INFORMATION WAS OBTAINED FROM SOURCES IN BELGIUM, CANADA, FRANCE, ITALY, JAPAN, SWEDEN AND THE FEDERAL REPUBLIC OF GERMANY. IN ADDITION, THE REPORT CONTAINS QUALITATIVE VALUE IMPACTS FOR THE PROPOSED RECOMMENDATIONS.

4. TI - REGULATORY ANALYSIS FOR USI A-1, 'WATER HAMMER'
AU - SERKIZ, A.W.
CS - NUCLEAR REGULATORY COMMISSION, WASHINGTON, D.C.
PU - MAR 84; 33P; FINAL REPT; SEE ALSO NUREG-0993; PC A03/MF A01
AB - NUREG-0993, REVISION 1 IS THE STAFF'S REGULATORY ANALYSIS DEALING WITH THE RESOLUTION OF THE UNRESOLVED SAFETY ISSUE A-1, WATER HAMMER. THIS REPORT CONTAINS THE VALUE-IMPACT ANALYSIS FOR THIS ISSUE, PUBLIC COMMENTS RECEIVED, AND STAFF RESPONSE, OR ACTION TAKEN, IN RESPONSE TO THOSE COMMENTS. THE STAFF'S TECHNICAL FINDINGS REGARDING WATER HAMMER IN NUCLEAR POWER PLANTS ARE CONTAINED IN NUREG-0927.

5. TI - EVALUATION OF WATER HAMMER OCCURRENCE IN NUCLEAR POWER PLANTS, TECHNICAL FINDINGS RELEVANT TO UNRESOLVED SAFETY ISSUE A-1.
AU - SERKIZ, A.W.
CS - NUCLEAR REGULATORY COMMISSION, WASHINGTON, D.C.
PU - MAR 84; 84P; FINAL REPT; SEE ALSO NUREG-0927; PC A05/MF A01
AB - THIS REPORT, WHICH INCLUDES RESPONSES TO PUBLIC COMMENTS, SUMMARIZES KEY TECHNICAL FINDINGS RELEVANT TO THE UNRESOLVED SAFETY ISSUE A-1, WATER HAMMER. THESE FINDINGS WERE DERIVED FROM STUDIES OF REPORTED WATER HAMMER OCCURRENCES AND UNDERLYING CAUSES AND PROVIDE KEY INSIGHTS INTO MEANS TO MINIMIZE OR ELIMINATE FURTHER WATER HAMMER OCCURRENCES.

6. TI - UNRESOLVED SAFETY ISSUES SUMMARY (AQUA BOOK), FEBRUARY 18, 1984 - May 18, 1984
CS - NUCLEAR REGULATORY COMMISSION, WASHINGTON, D.C.
PU - MAY 84; 55P; SEE ALSO NUREG-0606-V6-N1; PC A04/MF A01
AB - THE REPORT PROVIDES AN OVERVIEW OF THE STATUS OF THE PROGRESS AND PLANS FOR RESOLUTION OF THE GENERIC TASKS ADDRESSING 'UNRESOLVED SAFETY ISSUES' AS REPORTED TO CONGRESS.

7. TI - UNRESOLVED SAFETY ISSUES SUMMARY: AQUA BOOK.
CS - NUCLEAR REGULATORY COMMISSION, WASHINGTON, D.C.
PU - FEB 84; 55P; REPT. FOR 19 NOV 83-17 FEB 84; SEE ALSO NUREG-0606-V5-N4; PC A04/MF A01
AB - THE REPORT PROVIDES AN OVERVIEW OF THE STATUS OF THE PROGRESS AND PLANS FOR RESOLUTION OF THE GENERIC TASKS ADDRESSING 'UNRESOLVED SAFETY ISSUES' AS REPORTED TO CONGRESS.

8. TI - UNRESOLVED SAFETY ISSUES SUMMARY (AQUA BOOK), NOVEMBER 18, 1983
PU - NOV 83; 54P; SEE ALSO NUREG-0606-V5-N3; PC A04/MF A01
CS - NUCLEAR REGULATORY COMMISSION, WASHINGTON, D.C.
AB - THE REPORT PROVIDES AN OVERVIEW OF THE STATUS OF THE PROGRESS AND PLANS FOR RESOLUTION OF THE GENERIC TASKS ADDRESSING 'UNRESOLVED SAFETY ISSUES' AS REPORTED TO CONGRESS.

9. TI - UNRESOLVED SAFETY ISSUES SUMMARY (AQUA BOOK), AUGUST 19, 1983
CS - NUCLEAR REGULATORY COMMISSION, WASHINGTON, D.C.
PU - SEP 83; 54P; SEE ALSO NUREG-0606-V5-N2; PC A04/MF A01
AB - THE DOCUMENT PROVIDES AN OVERVIEW OF THE STATUS OF THE PROGRESS AND PLANS FOR RESOLUTION OF THE GENERIC TASKS ADDRESSING 'UNRESOLVED SAFETY ISSUES' AS REPORTED TO CONGRESS.

10. TI - VALUE-IMPACT ANALYSIS FOR USI (UNRESOLVED SAFETY ISSUE) A-1, 'WATER HAMMER'.
AU - SERKIZ, A.W.
CS - NUCLEAR REGULATORY COMMISSION, WASHINGTON, D.C.
PU - MAY 83; 28P; TECHNICAL REPT; PC A03/MF A01
AB - THIS REPORT PROVIDES THE STAFF'S VALUE-IMPACT ANALYSIS OF UNRESOLVED SAFETY ISSUE A-1, 'WATER HAMMER'. ALTHOUGH THIS ANALYSIS PROVIDES THE TECHNICAL BASIS FOR PROPOSED REVISIONS TO THE NRC STANDARD REVIEW PLAN (ALONG WITH NUREG-0927, 'FOR COMMENT'), THIS ANALYSIS DOES NOT REPRESENT A SUBSTITUTE FOR CURRENT RULES AND REGULATIONS.

11. TI - UNRESOLVED SAFETY ISSUES SUMMARY, AQUA BOOK.
CS - NUCLEAR REGULATORY COMMISSION, WASHINGTON, D.C.
PU - FEB 83; 50P; REPT. FOR 20 NOV 82-18 FEB 83; SEE ALSO NUREG-0606-V4-N1; PC A03/MF A01
AB - THE REPORT PROVIDES AN OVERVIEW OF THE STATUS OF THE PROGRESS AND PLANS FOR RESOLUTION OF THE GENERIC TASKS ADDRESSING 'UNRESOLVED SAFETY ISSUES' AS REPORTED TO CONGRESS.

12. TI - EVALUATION OF WATER HAMMER POTENTIAL IN PREHEAT STEAM GENERATORS.
AU - SEXTON, D.E.; KASAHARA, M.; UFFER, R.A.
CS - NUCLEAR REGULATORY COMMISSION, WASHINGTON, D.C.
PU - DEC 82; 42P; TECHNICAL REPT; PREPARED BY QUADREX CORP., CAMPBELL, CA; PC A03/MF A01
AB - AN EVALUATION OF THE DESIGN AND THE OPERATION OF PREHEAT STEAM GENERATORS WAS PERFORMED TO DETERMINE THE POTENTIAL RISK FOR DAMAGING WATER HAMMER DURING AUXILIARY FEEDWATER (AFW) OPERATION. IT WAS FOUND THAT THE POTENTIAL FOR SUCH A WATER HAMMER EVENT IS EXTREMELY LOW BECAUSE MULTIPLE COMPONENT FAILURES AND OPERATIONAL ERRORS ARE REQUIRED FOR THE WATER HAMMER TO OCCUR.

13. TI - UNRESOLVED SAFETY ISSUES SUMMARY (AQUABOOK)
CS - NUCLEAR REGULATORY COMMISSION, WASHINGTON, D.C.
PU - DEC 82; 50P; REPT. FOR 21 AUG 82-19 NOV 82; SEE ALSO NUREG-0606-V4-N3; PC A03/MF A01
AB - THIS PUBLICATION PROVIDES AN OVERVIEW OF THE STATUS OF THE PROGRESS AND PLANS FOR RESOLUTION OF THE GENERIC TASKS ADDRESSING 'UNRESOLVED SAFETY ISSUES' AS REPORTED TO CONGRESS.

14. TI - PREVENTION AND MITIGATION OF STEAM GENERATOR WATER HAMMER EVENTS IN PWR PLANTS.
AU - ANDERSON, NEWTON R.; HAN, JAMES T.
CS - NUCLEAR REGULATORY COMMISSION, WASHINGTON, D.C.
PU - NOV 82; 41P; PC A03/MF A01
AB - WATER HAMMER IN NUCLEAR POWER PLANTS IS AN UNRESOLVED SAFETY ISSUE UNDER STUDY AT THE NRC (USI A-1). ONE OF THE IDENTIFIED SAFETY CONCERNS IS STEAM GENERATOR WATER HAMMER (SGWH) IN PRESSURIZED-WATER REACTOR (PWR) PLANTS. THIS REPORT PRESENTS A SUMMARY OF: (1) THE CAUSES OF SGWH, (2) VARIOUS FIXES EMPLOYED TO PREVENT OR MITIGATE SGWH, AND (3) THE NATURE AND STATUS OF MODIFICATIONS THAT HAVE BEEN MADE AT EACH OPERATING PWR PLANT. THE NRC STAFF CONSIDERS THAT THE ISSUE OF SGWH IN TOP FEEDING DESIGNS HAS BEEN TECHNICALLY RESOLVED. THIS REPORT DOES NOT ADDRESS TECHNICAL FINDINGS RELEVANT TO WATER HAMMER IN PREHEAT TYPE STEAM GENERATORS.

15. TI - UNRESOLVED SAFETY ISSUES SUMMARY, AQUA BOOK
CS - NUCLEAR REGULATORY COMMISSION, WASHINGTON, D.C.
PU - SEP 82; 54P; REPT. FOR 21 MAY-20 AUG 82; SEE ALSO NUREG-0606-V4-N2; PC A04/MF A01
AB - THE UNRESOLVED SAFETY ISSUES SUMMARY IS DESIGNED TO PROVIDE THE MANAGEMENT OF THE NUCLEAR REGULATORY COMMISSION WITH A QUARTERLY OVERVIEW OF THE PROGRESS AND PLANS FOR COMPLETION OF GENERIC TASKS ADDRESSING UNRESOLVED SAFETY ISSUES REPORTED TO CONGRESS PURSUANT TO SECTION 210 OF THE ENERGY REORGANIZATION ACT OF 1974 AS AMENDED. THIS SUMMARY USES DATA COLLECTED FROM THE OFFICE OF NUCLEAR REACTOR REGULATION, OFFICE OF NUCLEAR REGULATORY RESEARCH, AND THE NATIONAL LABORATORIES AND IS PREPARED BY THE OFFICE OF RESOURCE MANAGEMENT.

16. TI - EVALUATION OF WATER HAMMER EVENTS IN LIGHT WATER REACTOR PLANTS
AU - UFFER, R.A.; BANERJEE, S.; BUCKHOLZ, F.B.; FRANKEL, M.; KASAHARA, M.
CS - EG & G IDAHIO, INC., IDAHO FALLS, USA
PU - JUL 82; 122P; TECHNICAL EVALUATION REPT; ALSO PUB. AS QUADREX CORP., CAMPBELL, CA. REPT. NO. QUAD-1-82-018; PC A06/MF A01
AB - THIS DOCUMENT PRESENTS THE RESULTS OF AN EVALUATION OF WATER HAMMER EVENTS IN LWR POWER PLANTS. THE EVALUATION WAS BASED UPON REPORTS OF ACTUAL EVENTS, TYPICAL PLANT DESIGN DRAWINGS AND OPERATION PROCEDURES. INCLUDED IN THIS REPORT ARE DESIGN AND OPERATING RECOMMENDATIONS FOR THE PREVENTION OR MITIGATION OF WATER HAMMER OCCURRENCE.

17. TI - COMPILATION OF DATA CONCERNING KNOWN AND SUSPECTED WATER HAMMER EVENTS IN NUCLEAR POWER PLANTS (CY 1969-MAY 1981).
AU - CHAPMAN, R.L.; CHRISTENSEN, D.D.; DAFOE, R.E.; HANNER, O.M.; WELLS M.E.
CS - EG & G IDAHO, INC., IDAHO FALLS, USA
PU - MAY 82; 295P; PC A13/MF A01
AB - THIS REPORT COMPILES DATA CONCERNING KNOWN AND SUSPECTED WATER HAMMER EVENTS REPORTED BY BWR AND PWR NUCLEAR POWER PLANTS IN THE UNITED STATES FROM JANUARY 1969 TO MAY 1981. THIS INFORMATION IS SUMMARIZED FOR EACH EVENT AND IS TABULATED FOR ALL EVENTS BY PLANT, PLANT TYPE, YEAR OF OCCURRENCE, TYPE OF WATER HAMMER, SYSTEM AFFECTED, BASIS/CAUSE FOR THE EVENT, AND DAMAGE INCURRED. INFORMATION IS ALSO INCLUDED FROM OTHER EVENTS NOT SPECIFICALLY IDENTIFIED AS WATER HAMMER RELATED. THESE EVENTS INVOLVED VIBRATION AND/OR SYSTEM COMPONENTS SIMILAR TO THOSE INVOLVED IN THE WATER HAMMER EVENTS. THESE OTHER EVENTS ARE INCLUDED TO ENSURE COMPLETENESS OF THE REPORT, BUT ARE NOT USED TO POINT OUT PARTICULAR FACTS OR TRENDS. ALSO, THIS REPORT DOES NOT EVALUATE FINDINGS WHICH CAN BE ABSTRACTED FROM THE DATA.

18. TI - UNRESOLVED SAFETY ISSUES SUMMARY (AQUA BOOK). VOLUME 3, NUMBER 1.
CS - NUCLEAR REGULATORY COMMISSION, WASHINGTON, D.C.
PU - FEB 81; 52P; REPT. FOR 7 NOV 80-13 FEB 81; PC A04

19. TI - WATER HAMMER IN NUCLEAR POWER PLANTS
CS - NUCLEAR REGULATORY COMMISSION, WASHINGTON, D.C.
PU - JUL 79; 90P; TECHNICAL REPT; PC A05/MF A01

20. TI - PWR FLECHT SEASET (PRESSURIZED WATER REACTOR FULL LENGTH EMERGENCY COOLING HEAT TRANSFER SEPARATE EFFECTS AND SYSTEMS EFFECTS TEST) SYSTEMS EFFECTS NATURAL CIRCULATION AND REFLUX CONDENSATION. DATA EVALUATION AND ANALYSIS REPORT.
AU - HOCHREITER, L.E.; RUPPRECHT, S.D.; DEDERER, J.T.; WONG, S.; ROSAL, E.R.
CS - WESTINGHOUSE ELECTRIC CORPORATION, PITTSBURGH, PA
PU - AUG 84; 586P; REPT. NO.14; PC A25/MF A01
AB - A SERIES OF NATURAL CIRCULATION TESTS WERE CONDUCTED AT A FLECHT SEASET FACILITY WHICH IS SCALED 1/307 BY VOLUME TO A FULL SIZE PWR. THE PURPOSE OF THESE TESTS WAS TO IDENTIFY HYDRAULIC AND HEAT TRANSFER PHENOMENA DURING NATURAL CIRCULATION COOLING MODES. THE RESULTING DATA, EVALUATION, AND ANALYSIS ARE TO BE USED FOR PWR CODES AND MODEL ASSESSMENTS AS WELL AS TO PROVIDE A COMPARISON TO SIMILAR EXPERIMENTS IN OTHER SCALED SYSTEMS. STEADY-STATE SINGLE-PHASE, TWO-PHASE, AND REFLUX CONDENSATION MODES OF NATURAL CIRCULATION COOLING WERE ESTABLISHED IN THE FLECHT SEASET SYSTEMS EFFECTS FACILITY AND THE FLOW AND HEAT TRANSFER CHARACTERISTICS OF THE DIFFERENT COOLING MODES WERE IDENTIFIED. THIS REPORT PRESENTS THE TEST DATA; DATA REDUCTION, ANALYSIS, AND EVALUATIONS; AND RESULTING MODEL DEVELOPMENT AND ANALYSIS.

21. TI - PWR (PRESSURIZED WATER REACTOR) FLECHT SEASET (FULL LENGTH EMERGENCY COOLING HEAT TRANSFER SEPARATE EFFECTS AND SYSTEMS EFFECTS); SYSTEMS EFFECTS NATURAL CIRCULATION AND REFLUX CONDENSATION TASK PLAN REPORT.
AU - ROSAL, E.R.; HOCHREITER, L.E.; ANDREYCHEK, T.S.; LEE, N.; RUPPRECHT, S.D.
CS - NUCLEAR REGULATORY COMMISSION, WASHINGTON, D.C.
PU - FEB 83; 413P; REPT. NO. 12; PC A18/MF A01
AB - THIS REPORT PRESENTS A DESCRIPTIVE PLAN OF TESTS FOR THE SYSTEMS EFFECTS TASK OF THE FULL LENGTH EMERGENCY COOLING HEAT TRANSFER SEPARATE EFFECTS AND SYSTEMS EFFECTS (FLECHT SEASET) PROGRAM. THIS TASK IS DESIGNED TO PRODUCE EXPERIMENTAL DATA WHICH CAN BE USED TO ADDRESS ISSUES RELATED TO NATURAL CIRCULATION COOLING MODES IN A PRESSURIZED WATER REACTOR (PWR). THE NATURAL CIRCULATION TESTS WERE PLANNED IN DIRECT RESPONSE TO THE ACCIDENT AT THREE MILE ISLAND. THE TESTS CONSIST OF NATURAL CIRCULATION AND REFLUX CONDENSATION COOLING EXPERIMENTS USING ELECTRIC HEATING RODS TO SIMULATE CURRENT NUCLEAR CORE ARRAYS OF PWR AND PWR FUEL VENDORS. THE FLECHT SEASET SYSTEMS EFFECTS TEST FACILITY WITH A SCALE FACTOR OF 1/307 WITH RESPECT TO A FOUR-LOOP 3411 MWT PWR WAS USED. THE FACILITY WAS DESIGNED WITH ALL ELEVATIONS IDENTICAL TO THOSE OF A PWR. TWO FULL HEIGHT STEAM GENERATORS WITH ACTIVE SECONDARY SIDE HEAT REMOVAL ARE ALSO PART OF THE SYSTEM DESIGN. ALL TESTS WERE CONDUCTED WITH A COUSINE AXIAL POWER PROFILE. THE DATA OBTAINED FROM THESES TESTS WILL BE USED TO EVALUATE THE EFFECTS OF COMPONENTS AND SYSTEMS PARAMETERS DURING NATURAL CIRCULATION COOLING MODES.

22. TI - SAFETY EVALUATION REPORT FOR THE MARK I CONTAINMENT LONG-TERM PROGRAM - RESOLUTION OF GENERIC TECHNICAL ACTIVITY A-7. SUPPLEMENT NUMBER 1.
CS - NUCLEAR REGULATORY COMMISSION, WASHINGTON, D.C.
PU - AUG 82; 23P; SUPPLEMENT TO NUREG-0661; PC A02/MF A01
AB - NUREG-0661 WAS ORIGINALLY ISSUED IN JULY 1980 WITH FOUR OPEN ITEMS WHICH HAVE NOW BEEN RESOLVED. THE FOUR OPEN ITEMS CONSISTED OF THE DOWNCOMER OSCILLATION LOAD DEFINITION AND THE CONFIRMATORY ANALYSES AND TEST PROGRAMS WHICH WERE INTENDED TO JUSTIFY THE ADEQUACY OF THE LOAD SPECIFICATION. THE CONFIRMATORY EFFORTS CONCERN THE ASSESSMENT OF COMPRESSIBLE FLOW EFFECTS IN THE SCALED POOL SWELL TESTS AND THE CONFIRMATION OF CONDENSATION OSCILLATION LOAD MAGNITUDE AND GLOBAL SYMMETRY. THE STAFF HAS REVIEWED THE IMPROVED DOWNCOMER CONDENSATION OSCILLATION LOAD DEFINITION PROVIDED BY THE MARK I OWNERS' GROUP AND FIND IT ACCEPTABLE. THE STAFF HAS ALSO REVIEWED THE CONFIRMATORY EXPERIMENTAL AND ANALYTICAL PROGRAMS CONDUCTED BY THE MARK I OWNERS' GROUP AND HAVE CONCLUDED THAT THE ADEQUACY OF THE VARIOUS LOAD SPECIFICATIONS HAVE BEEN JUSTIFIED. THIS SUPPLEMENT NO. 1 TO NUREG-0661 THEREFORE SERVES AS THE STAFF'S FINAL RESOLUTION OF UNRESOLVED SAFETY ISSUE A-7.

23. TI - WATER HAMMER, FLOW INDUCED VIBRATION AND SAFETY/RELIEF VALVE LOADS
CS - EG AND G. IDAHO, INC., IDAHO FALLS, USA
PU - SEP 84; 81P; FINAL REPT; ALSO PUB. AS QUADREX CORP., CAMPBELL, CA> REPT. NO. QUAD-1-84-109; PC A05/MF A01
AB - THIS REPORT PRESENTS THE RESULTS OF AN EVALUATION PERFORMED TO DETERMINE CURRENT AND RECOMMENDED PRACTICES REGARDING THE CONSIDERATION OF WATER HAMMER FLOW-INDUCED VIBRATION AND SAFETY-RELIEF VALVE LOADS IN THE DESIGN OF NUCLEAR POWER PLANT PIPING SYSTEMS. CURRENT PRACTICES WERE DETERMINED BY A SURVEY OF INDUSTRY EXPERTS. RECOMMENDED PRACTICES WERE DETERMINED BY A SURVEY OF INDUSTRY EXPERTS. RECOMMENDED PRACTICES WERE DETERMINED BY EVALUATING FACTORS SUCH AS LOAD MAGNITUDE AND FREQUENCY CONTENT,SYSTEM SUSCEPTIBILITY TO LOADS, FREQUENCY OF LOAD OCCURRENCE AND SAFETY EFFECTS OF POSTULATED PIPING DAMAGE. THIS REPORT WAS PREPARED FOR USE BY THE NRC STAFF IN DEVELOPING POSITIONS REGARDING CONSIDERATION OF DYNAMIC PIPING LOADS FOR USE BY THE NRC'S PIPING REVIEW COMMITTEE.

24. TI - INVESTIGATION OF COLD LEG WATER HAMMER IN A PWR (PRESSURIZED WATER REACTOR) DUE TO THE ADMISSION OF EMERGENCY CORE COOLING (ECC) DURING A SMALL BREAK LOCA (LOSS-OF-COOLANT ACCIDENT).
AU - JACKOBEK, A.B.; GRIFFITH, P.
CS - MASSACHUSETTS INSTITUTE OF TECHNOLOGY, CAMBRIDGE, USA, DEPT OF MECHANICAL ENGINEERING
PU - SEP 84; 60P; TECHNICAL REPT; PC A04/MF A01
AB - EXPERIMENTAL STUDIES USING A PROTOTYPICAL FLOW MODEL OF A PRESSURIZED WATER REACTOR (PWR) DEMONSTRATE WATER HAMMER IN THE COLD LEGS DUE TO THE ADMISSION OF EMERGENCY CORE COOLING (ECC). SUCH WATER HAMMER CAN OCCUR IN AN ACTUAL PWR DURING REFLOOD PROVIDED THERE EXISTS A STRATIFIED FLOW OF STEAM AND WATER IN THE COLD LEGS. THE HYDRAULIC ARE POSTULATED IN THIS REPORT. CALCULATIONS, BASED ON A PUBLISHED CRITERION FOR WATER HAMMER INITIATION, SHOW THAT THE

AMOUNT OF ECC ADMINISTERED BY THE HIGH PRESSURE SAFETY INJECTION (HPSI) SYSTEM, IS NOT GREAT ENOUGH TO PRODUCE LIQUID DEPTHS IN THE COLD LEG WHICH CAN LEAD TO SLUG FORMATION AND SUBSEQUENT STEAM BUBBLE COLLAPSE WATER HAMMER. HOWEVER, A FEW WATER HAMMERS CAN OCCUR DURING ECC AS THE COLD LEG IS BEING REFILLED. A SIMPLE ANALYSIS DEVELOPED IN THIS REPORT CALCULATES THE WATER HAMMER PRESSURES POSSIBLE UNDER THESE POSTULATED FLOW CONDITIONS.

25. TI - AN EVALUATION OF PWR STEAM GENERATOR WATER HAMMER.
AU - BLOCK, J.A.; CROWLEY, C.J.; ROTHE, P.H.; WALLIS, G.B.; YOUNG, L.R.
CS - CREARE, INC., HANOVER, N.H.; NUCLEAR REGULATORY COMMISSION, WASHINGTON, D.C.
PU - JUN 77; 336P; FINAL TECHNICAL REPT. 1 JUN-31 DEC 76; PC A15/MF A01

26. TI - THE SIGNIFICANCE OF WATER HAMMER EVENTS TO PUBLIC DOSE FROM REACTOR ACCIDENTS: A PROBABILISTIC ASSESSMENT.
AU - AMICO, P.J. (APPLIED RISK TECHNOLOGY CORP., COLUMBIA, MD (USA)); FERRELL, W.L. (SCIENCE APPLICATIONS, INC., ALBUQUERQUE, NM (USA)); RUBIN, M.P. (NUCLEAR REGULATORY COMMISSION, WASHINGTON, DC (USA)). ; 9500754; 9500870 BORK, G.; RININSLAND, H. (KERNFORSCHUNGSZENTRUM KARLSRUHE G.M.B.H. (GERMANY, F.R.). PROJEKT NUKLEARE SICHERHEIT). 9200307
PU - P. 2000-2008. 5TH INTERNATIONAL MEETING ON THERMAL NUCLEAR REACTOR SAFETY. PROCEEDINGS. VOL. 3. DEC 1984. 736 P.
CO - INTERNATIONAL MEETING ON THERMAL NUCLEAR SAFETY, KARLSRUHE, GERMANY, 9-13 SEPT, 1984

27. TI - INITIATION OF WATERHAMMER IN HORIZONTAL AND NEARLY HORIZONTAL PIPES CONTAINING STEAM AND SUBCOOLED WATER.
AU - BJORGE, R.W. (GENERAL ELECTRIC CO., LYNN, MA); GRIFFITH, P. HSU, Y.Y.; LEE, R. (COMPS.).
OR - NUCLEAR REGULATORY COMMISSION, WASHINGTON, DC (USA). 9500870
PU - P. 385-415. JOINT NRC/ANS MEETING ON BASIC THERMAL-HYDRAULIC MECHANISMS IN LWR ANALYSIS. APR 1983.

9.2 AMERICAN NUCLEAR SOCIETY

1. TI - PROCEEDINGS OF THE JOINT NRC/ANS (NUCLEAR REGULATORY COMMISSION/AMERICAN NUCLEAR SOCIETY) MEETING ON BASIC THERMAL HYDRAULIC MECHANISMS IN LWR (LIGHT WATER REACTOR) ANALYSIS HELD AT BETHESDA, MARYLAND ON SEPTEMBER 14-15, 1982
PU - APR 83; 613P; SPONSORED IN PART BY AMERICAN NUCLEAR SOCIETY, WASHINGTON, DC; PC A99/MF A01
AB - THIS MEETING FOCUSES ON BASIC THERMAL HYDRAULIC MECHANISMS OF CONCERN TO REACTOR SAFETY STUDIES AND ACCIDENT EVALUATION. TOPICS FOR IN-DEPTH DISCUSSION INCLUDE - BASIC SCALING PRINCIPLES FOR TWO-PHASE FLOW - BECAUSE OF THE CURRENT LACK OF GENERALLY ACCEPTED SCALING PRINCIPLES USED FOR VARIOUS TEST FACILITIES ARE CRITICALLY REVIEWED TO ARRIVED AT A CONSENSUS SET OF PRINCIPLES IN WHICH IMPORTANT PHENOMENA AND CONTROLLING PARAMETERS ARE PRESERVED. CONDENSATION-INDUCED INSTABILITY - THE MECHANISMS ASSOCIATED WITH THE INSTABILITIES GENERATED BY CONDENSATION SHOCK PHENOMENA, WHEN COLD ECCS WATER COMES IN CONTACT WITH STEAM, ARE REVIEWED. SPECIAL EFFECTS ON CORE THERMAL HYDRAULICS - THE EFFECT ON HEAT TRANSFER IN THE REACTOR COOLING SYSTEM, DUE TO SUCH FACTORS AS BLOCKAGE, GRID SPACERS, AND THE PRESENT OR NON-CONDENSABLES, ARE DISCUSSED.

2. TI - WATERHAMMER IN BWR CONTROL ROD DRIVE PIPING SYSTEMS
AU - SEMPRUCCI, L.B.
PU - TRANS. AM. NUCL. SOC. (USA), 1984, 46(1), P. 96
AB - WATERHAMMER IN SMALL-BORE PIPING, SUCH AS A 0.75- OR 1-IN. PIPE, IS NOT GENERALLY THOUGHT TO BE OF MUCH CONCERN. THIS IS SO BECAUSE THE RESULTANT WATERHAMMER LOADS OF 50 TO 100 LB ARE EASILY ACCOMMODATED BY THE SIMPLE SUPPORTS USED IN PIPING OF THIS SIZE. HOWEVER, WHEN 50 OR MORE OR THESE SMALL BORE PIPES ARE GANG SUPPORTED, AS IS THE TECHNIQUE IN BWR CONTROL ROD DRIVE MECHANISMS, THE 50- TO 100LB LOAD BECOMES A 2500- TO 5000-LB LOAD. THESE LOADS MUST BE CONSIDERED IN THE SUPPORT ANALYSIS AND THEREFORE A WATERHAMMER ANALYSIS IS OF GREAT CONCERN.

3. TI - WATERHAMMER PHENOMENA IN LOFT REACTOR SECONDARY COOLING SYSTEM
AU - HUNTER, J.A.
PU - TRANS. AM. NUCL. SOC. (USA), 1979, VOL.33, 777-8

4. TI - ANALYSIS OF BWR-RHR SYSTEM WATER HAMMER FOLLOWING COINCIDENT LOCA AND LOOP EVENTS
AU - YIH, T.S.; CAJIGAS, J.M.; BUNKER, P.L.; WITMAN, P.M.
PU - TRANS. AM. NUCL. SOC. (USA), 1987, VOL.55, P 735-7
AB - FOLLOWING A BOILING WATER REACTOR (BWR) DESIGN-BASIS LOSS-OF-COOLANT ACCIDENT (LOCA) COINCIDENT WITH A LOSS-OF-OFFSITE POWER (LOOP) WHILE ONE OR BOTH OF THE RESIDUAL HEAT REMOVAL (RHR) LOOPS ARE ALIGNED FOR SUPPRESSION POOL COOLING, THE RHR SYSTEM IS REQUIRED TO BE RAPIDLY REALIGNED FROM THE POOL COOLING MODE TO THE LOW-PRESSURE CORE INJECTION MODE. AFTER THE POWER LOSS AND RHR PUMPS SHUT OFF, PORTIONS OF THE RHR SYSTEM WILL VOID AS PART OF THE INVENTORY DRAINS INTO THE SUPPRESSION POOL AS A RESULT OF ELEVATION DIFFERENCES. WHEN DIESEL GENERATOR POWER BECOMES AVAILABLE, THE SUBSEQUENT RESTART OF

THE RHR PUMPS AGAINST A PARTIALLY VOIDED PIPING SYSTEM IS EXPECTED TO PRODUCE WATERHAMMER THROUGH LARGE PORTIONS OF THE SYSTEM. THE PURPOSE OF THIS PAPER IS TO DEVELOP THE POTENTIAL INITIAL CONDITIONS FOR THIS EVENT AND EVALUATE THE EFFECTS ON THE RHR PIPING SYSTEM.

5. TI - WATER HAMMER EXPERIENCES IN THE STARTUP AND EARLY OPERATION OF THE SHEARON HARRIS PLANT
AU - CASADA, D.
PU - TRANS. AM. NUCL. SOC. (USA), 1987. VOL.55, P 735
AB - DURING THE STARTUP TESTING AND INITIAL OPERATION OF ANY POWER PLANT, SYSTEMS UNDERGO PLANNED TRANSIENTS TO CONFIRM THEIR ABILITY TO RESPOND AS DESIGNED. IN ADDITION TO PLANNED TESTING, UNPLANNED TRANSIENTS INFREQUENTLY OCCUR AS EQUIPMENT IS INITIALLY USED. SOME OR BOTH THE PLANNED AND UNPLANNED TRANSIENTS RESULT IN WATER-HAMMER EVENTS. SEVERAL WATER HAMMER EVENTS EXPERIENCES DURING PREOPERATIONAL RESTING, POWER ASCENSION TESTING, AND EARLY OPERATION OR THE SHEARON HARRIS NUCLEAR POWER PLANT ARE PRESENTED. THE CAUSE, EFFECTS, AND CORRECTIVE ACTIONS UNDERTAKEN TO PREVENT RECURRENCE FOR EACH EVENT DISCUSSED ARE PROVIDED. IN ADDITION, EXAMPLES OF PREVENTIVE MEASURES TAKEN, BASED ON INDUSTRY EXPERIENCE ACCRUED AT OTHER PLANTS, TO PREVENT A SIMILAR OCCURRENCE AT SHEARON HARRIS ARE DISCUSSED.

6. TI - WATER HAMMER PREVENTION, MITIGATION, AND ACCOMMODATION - A PERSPECTIVE
AU - KIM, J.H.
PU - TRANS. AM. NUCL. SOC. (USA), 1987, VOL.55, P 733-4
AB - PRESENTS AN INDUSTRY PERSPECTIVE ON WATER HAMMER, REVISITS THE ISSUES, AND RENEWS INTEREST IN THIS AREA WITH THE AIM TO PREVENT, MITIGATE, AND ACCOMMODATE WATER HAMMER.

7. TI - A REVIEW AND ASSESSMENT OF RECENT WATER HAMMER OCCURRENCES
AU - LEEDS, E.J.; LAM, P
PU - TRANS. AM. NUCL. SOC. (USA), 1987, VOL.55, P 731-3
AB - POTENTIAL SAFETY CONCERNS ASSOCIATED WITH WATER HAMMER OCCURRENCES IN OPERATING NUCLEAR PLANTS ARE PRIMARILY RELATED TO THE FREQUENCY AND SEVERITY OF THE WATER HAMMER OCCURRENCES, THE LEVEL OF DAMAGE INCURRED DUE TO HYDRAULIC LOADS, AND THE SAFETY FUNCTION OF THE SYSTEM INVOLVED. THESE SAFETY CONCERNS WERE EVALUATED BY THE US NUCLEAR REGULATORY COMMISSION IN THE COURSE OF RESOLVING UNRESOLVED SAFETY ISSUE A-1, 'WATER HAMMER'. THE AUTHORS REVIEW THE DATA ON LWR WATER HAMMER EVENTS AND DISCUSS THE EFFECTIVENESS OF THE CORRECTIVE ACTIONS.

8. TI - A FINITE ELEMENT SOLUTION FOR PRESSURE AND VELOCITY WAVE PROPAGATION
AU - LUCAS, S.
PU - TRANS. AM. NUCL. SOC. (USA) 1987; VOL. 55; P. 68709; 4 REFS
AB - AS PART OF THE DEVELOPMENT OF UTILITY THERMAL-HYDRAULICS CAPABILITIES, THE MICROCOMPUTER IS BECOMING A MORE POWERFUL TOOL FOR ANALYSIS. WATER HAMMER AND SINGLE-PHASE FLOW PROBLEMS HAVE BEEN ANALYZED WITH LARGE COMPUTER CODES SUCH AS RELAP5, TRAC, OR METHOD OF CHARACTERISTICS CODES. THESE ANALYSES CAN NOW BE PERFORMED ON A MICROCOMPUTER FOR A FRACTION OF THE MANPOWER AS BEFORE AND AT

ESSENTIALLY NO COST. THIS CAN BE DONE BY USING FINITE ELEMENT (WEIGHTED RESIDUAL) TYPES OF METHODS. A FINITE ELEMENT (WEIGHTED RESIDUAL) TYPE OF SOLUTION IS OUTLINED FOR SOLVING THE CONTINUITY (MASS) AND MOMENTUM EQUATIONS FOR PRESSURE WAVE PROPAGATION. THE METHOD USES A STAGGERED GRID. A STAGGERED GRID IS ONE IN WHICH THE SCALAR VARIABLES (SUCH AS PRESSURE) AND VECTOR VARIABLES (VELOCITY, MASS FLUX) ARE SOLVED FOR AT DIFFERENT POINTS IN THE COMPUTATIONAL GRID. THE METHOD PRESENTED HERE IS TERMED THE 'ELIMINATION' METHOD, SINCE FOR TWO EQUATION (MASS AND MOMENTUM), ONE OF THE RESULTING IN, ESSENTIALLY, A HIGHER ORDER EQUATION IN ONE DEPENDENT VARIABLE.

9. TI - A STUDY OF WATER HAMMER DUE TO A SUDDEN STEAM BUBBLE COLLAPSE USING THE CHARACTERISTICS METHOD
AU - DAVIS, F.J.,JR.; HASSAN, Y.A.
PU - TRANS. AM. NUCL. SOC. (USA) 1987; VOL. 55; P. 561-3; 3 REFS
AB - THE AUTHORS PRESENT A NUMERICAL PROGRAM DEVELOPED FOR ESTIMATING THE TIME DEPENDENT PRESSURE RESPONSE TO STEAM BUBBLE COLLAPSE. THE METHOD OF CHARACTERISTICS IS UTILIZED TO DETERMINE PRESSURE PROPAGATION DUE TO WATER HAMMER.

10. TI - SAN ONOFRE UNIT 1 LOSS-OF-OFF-SITE-POWER WATER HAMMER EVENT
AU - KATZ, B.
PU - TRANS. AM. NUCL. SOC. (USA) 1987; VOL. 54, SUPPL. 1; P. 67; 0 REFS
AB - THE AUTHOR SUMMARIZES THE LOSS-OF-OFF-SITE-POWER-AND-WATER HAMMER EVENT THAT OCCURRED AT SAN ONOFRE UNIT 1 ON NOVEMBER 21, 1985. UNIT 1 IS A 450-MW (ELECTRIC) PRESSURIZED WATER REACTOR, SUPPLIED BY WESTINGHOUSE, THAT BEGAN COMMERCIAL OPERATION IN JANUARY 1968.

11. TI - LESSONS LEARNED FROM THE SONGS UNIT 1 WATER HAMMER EVENT
AU - CHIU, C.
PU - TRANS. AM. NUCL. SOC. (USA) 1987; VOL.54; P. 289-91; 4 REFS
AB - ON NOVEMBER 21, 1985, A WATER HAMMER EVENT OCCURRED IN HORIZONTAL FEEDWATER LINE B AT SAN ONOFRE NUCLEAR GENERATION SITE (SONGS) UNIT 1. THE SONGS UNIT 1 IS A THREE-LOOP PRESSURIZED WATER REACTOR DESIGNED BY WESTINGHOUSE ELECTRIC CORPORATION. THE EVENT WAS INITIATED BY A DIFFERENT CURRENT TRIP ON THE BUS OF AUXILIARY TRANSFORMER C. THE ROOT CAUSE OF THE EVENT WAS A SIMULTANEOUS FAILURE OF FIVE CHECK VALVES IN THE FEEDWATER SYSTEM. TWO OF THEM ARE LOCATED DOWNSTREAM OF THE FEEDWATER PUMP, AND THREE OF THEM ARE LOCATED FURTHER DOWNSTREAM AND ON THE LINES TO THE STEAM GENERATORS. THE FAILURE MECHANISM WAS DETERMINED TO BE FLOW-INDUCED VIBRATION, WHICH CAUSED REPEATED IMPACT BETWEEN THE DISK STUD AND THE DISK STOP. THE WATER HAMMER OCCURRED IN FEEDWATER LINE B DURING THE REFILLING OF FEEDWATER LINES A, B, AND C WITH AUXILIARY FEEDWATER.

12. TI - A NEW SCENARIO FOR INTERSYSTEM LOCAS IN BRWS
AU - CHU, T.L.; STOYANOV, S.
PU - TRANS. AM. NUCL. SOC. (USA) 1986; VOL.53; P. 348-9; 3 REFS
AB - THE PURPOSE OF THE WORK IS TO ANALYZE THE SCENARIO OF INTERSYSTEM LOSS-OF-COOLANT ACCIDENTS (LOCAS) IN THE FEEDWATER LINES OF BOILING WATER REACTORS (BWRS), IN LIGHT OF THE WATER HAMMER EVENT AT SAN ONOFRE, UNIT 1. SUCH SCENARIO HAS A POTENTIAL FOR HIGH FREQUENCY

AND HIGH CONSEQUENCE. THE FREQUENCY IS POTENTIALLY HIGH BECAUSE A SIMILAR EVENT HAS OCCURRED; THE CONSEQUENCE IS HIGH CONTAINMENT IS BYPASSED.

13. TI - STEAM GENERATOR VESSEL AND FEEDWATER LINE INTEGRITY ISSUES
AU - BAMFORD, W.H.
PU - TRANS. AM. NUCL. SOC. (USA) 1986; VOL. 53; P. 208-9; 5 REFS
AB - THE AUTHOR DISCUSSES THREE OPERATIONAL ISSUES THAT HAVE OCCURRED IN THE STEAM GENERATOR PRESSURE BOUNDARY AND DETAILS THE IMPROVEMENTS THAT WERE DEVELOPED TO HELP PROTECT AGAINST FUTURE OCCURRENCE. THE ISSUES ARE FEEDWATER LINE CRACKING, WATER HAMMER, AND GIRTHWELD CRACKING OF THE STEAM GENERATOR SHELL.

14. TI - WATER HAMMER IN A PWB HORIZONTAL FEEDWATER LINE
AU - CHONG CHIU; TUTTLE, D.; SERKIZ, A.W.
PU - TRANS. AM. NUCL. SOC. (USA) 1986; VOL. 52; P. 589-90; 6 REFS
AB - THE AUTHORS DELINEATE THE SEQUENCE OF A WATER HAMMER EVENT THAT OCCURRED ON NOVEMBER 21, 1985, SAN ONOFRE UNIT 1 AND PRESENTS THE RESULTS OF AN ANALYSIS THAT IDENTIFIES THE CONDITIONS NECESSARY TO INITIATE A WATER HAMMER IN A LONG, HORIZONTAL FEEDWATER LINE. BASED ON THE FINDINGS OF THE ANALYSIS, IT HAS BEEN DETERMINED THAT A WATER HAMMER IN A PARTIALLY VOIDED FEEDWATER LINE CAN BE AVOIDED IF THE INJECTED AUXILIARY FEEDWATER FLOW RATE IS GREATER THAN AN UPPER LIMIT OR LESS THAN A LOWER LIMIT

15. TI - MECHANISTIC PIPE BREAK EVALUATION OF PWR AUXILIARY PIPING
AU - SWAMY, S.A.; CHIRIGOS, J.N.
PU - TRANS. AM. NUCL. SOC. (USA) 1984; 46(1); P.39-40; 0 REFS
AB - WESTINGHOUSE HAS DEVELOPED A METHODOLOGY FOR JUSTIFYING THE ELIMINATION OF LARGE PIPE BREAKS IN THE PRESSURIZED WATER REACTOR (PWR) COOLANT SYSTEM PRIMARY LOOP AS A DESIGN BASIS. IN GENERAL, THIS METHODOLOGY CAN BE EXPENDED TO THE LARGE-DIAMETER AUXILIARY PIPING SYSTEMS SUCH AS THE PRESSURIZER SURGE PIPING SYSTEM, RESIDUAL HEAT REMOVAL SYSTEM, ACCUMULATOR PIPING SYSTEM, AND MAIN STEAMLINE PIPING SYSTEM. HOWEVER, CONSIDERATION OF AUXILIARY PIPING SYSTEMS DIFFERS FROM THE REACTOR COOLANT SYSTEM IN SEVERAL ASPECTS INCLUDING DIFFERENCES IN MATERIALS, FATIGUE CRACK GROWTH EFFECTS, AND CONSIDERATION OF THEIR FAILURE MECHANISMS SUCH AS THERMAL STRIPING AND WATER HAMMER LOADS. IN ADDITION, FOR STEAM LINES, THE ESTIMATED LEAK RATES ARE USUALLY SMALL WHEN EXAMINED IN LIGHT OF CURRENTLY AVAILABLE LEAK DETECTION CRITERIA, THUS IDENTIFYING THE NEED FOR ADDITIONAL LEAK DETECTION CRITERIA. TYPICAL ANALYTICAL RESULTS AND ECONOMIC BENEFITS PERTAINING TO AUXILIARY PIPINGS SYSTEMS, ARE DISCUSSED.

16. TI - CONTROL ROD DRIVE WATER HAMMER IN BOILING WATER REACTORS
AU - STRONG, B.R., JR; LEUNG, J.H.; LIP-BU TAN
PU - TRANS. AM. NUCL. SOC. (USA) 1983; VOL. 44; P. 621-2
AB - WATER HAMMER IS A COMMON OCCURRENCE IN LIQUID PIPING SYSTEMS, SOMETIMES CAUSING RUPTURE OF THE PIPE OR DAMAGE TO STRUCTURAL MEMBERS WHEN THE CONTROLLING MECHANICAL EQUIPMENT FAILS OR ACTS TOO QUICKLY. NUCLEAR POWER PLANTS ARE NOT IMMUNE TO WATER HAMMER OR OTHER FLUID TRANSIENTS AND 'HAMMERING' IS OFTEN OBSERVED IN

HYDRAULIC SYSTEMS REQUIRED TO OPERATED VERY QUICKLY FOR SAFETY REASONS. THE CONTROL ROD DRIVE HYDRAULIC SYSTEMS (CRDHS) IN BOILING WATER REACTORS (BWRS), WHICH CONTROL THE NUCLEAR FISSION AND HEAT BUILDUP INSIDE THE REACTOR, ARE AMONG THE COMPUTER SIMULATION, VERIFIED BY IN-PLANT TESTS, HAVE EXPLORED THE UNIQUE AND UNUSUALLY SEVERE WATER HAMMER IN 'FAST-SCRAM' BWR-6 GENERAL ELECTRIC REACTOR CRD SYSTEMS, AND HAVE DEVELOPED PROCEDURES TO CALCULATE THE RESULTING FIELD LOADINGS.

17. TI - SIMPLIFIED METHOD OF ESTIMATING WATER HAMMER LOADS
AU - LEUNG, J.H.; STRONG, B.R., JR.
PU - TRANS. AM. NUCL. SOC. (USA) 1983; VOL. 44; PL 619-21; 5 REFS.
AB - STRUCTURAL DAMAGE AND PIPE FAILURE ATTRIBUTED TO WASTE HAMMER EVENTS HAVE BEEN REPORTED IN ALL TYPES OF PIPING SYSTEMS AND HAVE BEEN GAINING INCREASING CONSIDERATION IN RECENT YEARS. ONE OF THE MOST COMMONLY KNOWN WATER HAMMER EVENTS IN OPERATING PLANTS IS THE FLUID TRANSIENT IN A FLUID SYSTEM CAUSED BY VALVE CLOSURE OR OPENING. THE CLOSURE OR OPENING OF A VALVE IN A FLUID SYSTEM GENERATES PRESSURE WAVES IN THE FLUID, WHICH TRANSLATE TO ITS CONTAINERS AS UNBALANCED FORCES ON LOCAL PIPE SEGMENTS. THE BEST WAY TO ASSURE THE LONG-TERM SURVIVAL OF THE PIPING AND SUPPORTS IS TO DETERMINE THE ENTIRE PIPING RESPONSE DURING THE DESIGN STAGES. TO DESIGN SUPPORTS TO MITIGATE THE FAILURE OF THE PIPING SYSTEMS AND SUPPORTS DUE TO THESE EVENTS, WATER HAMMER LOADS, PIPING SUPPORT REACTION FORCES, AND PIPE STRESSES NEED TO BE ESTIMATED. PREVIOUSLY, ONLY THE PEAK PRESSURE COULD BE ESTIMATED THROUGH THE USE OF SIMPLE HAND CALCULATIONS; PIPING AND SUPPORT LOADS HAVE REQUIRED EXPENSIVE AND TIME-CONSUMING DYNAMIC ANALYSIS. NOW, THESE WATER HAMMER LOADS CAN BE ESTIMATED WITHOUT COMPUTER ANALYSIS.

18. TI - AN EVALUATION OF WATER HAMMER IN NUCLEAR POWER PLANTS
AU - SERKIZ, A.W.; MERILO, M.
PU - THERMAL-HYDRAULICS OF NUCLEAR REACTORS. SECOND INTERNATIONAL TOPICAL MEETING ON NUCLEAR REACTOR THERMAL-HYDRAULICS PUBL - LAGRANGE PARK, IL, USA; ANS 1982; P. 803-6 VOL. 2; XIV+1525 P.; 6 REFS
AB - WATER HAMMER CAN OCCUR AS A RESULT OF STEAM-VOID COLLAPSE, STEAM-DRIVEN SLUGS OF WATER, PUMP STARTUP INTO VOIDED LINES, AND INADVERTENT CLOSURES OF VALVES; THE RESULT IS LARGE HYDRAULIC PRESSURE LOADS. SINCE 1968, ABOUT 150 WATER HAMMER EVENTS HAVE BEEN REPORTED IN USA NUCLEAR POWER PLANTS; DAMAGE HAS BEEN CONFINED TO PIPE HANGERS AND SNUBBERS. THE INCREASE IN REPORTED WATER HAMMER EVENTS IN THE 1970'S LED TO THE DESIGNATION OF WATER HAMMER AS UNRESOLVED SAFETY ISSUE A-1 IN 1979. SINCE THE MID-1970'S REPORTED OCCURRENCES AND THEIR OPERATIONAL MEASURES HAVE BEEN IMPLEMENTED. THIS PAPER PRESENTS THE RESULTS OF GENERIC EVALUATIONS OF WATER HAMMER OCCURRENCE AND REPORTED DAMAGE AND SETS FORTH TECHNICAL FINDINGS. THESES FINDINGS INDICATE THAT GOOD DESIGN PRACTICES AND OPERATIONAL PROCEDURES CAN MINIMIZE THE OCCURRENCE OF WATER HAMMER.

19. TI - AN ANALYTICAL APPROACH TO THE EVALUATION OF WATER HAMMER PHENOMENA
AU - LAHEY, R.T., JR.; DREW, D.A.
PU - TRANS. AM. NUCL. SOC. (USA) NOV. 1980; VOL. 35; P. 627-9; 2 REFS

20. TI - SIMULATION OF PHENOMENA IN A PRESSURE SUPPRESSION SYSTEM WITH THE CODE DRASYS
AU - SCHALLY, P.
PU - TRANS. AM. NUCL. SOC. (USA)
1979 ; VOL.31 ; 397-8

21. TI - NUMERICAL PREDICTION OF THE DYNAMIC STABILITY OF BOILING CHANNELS
AU - SAMI, S.M.
PU - TRANSACTIONS OF THE AMERICAN NUCLEAR SOCIETY
1988; VOL.56; P. 390-2; 16 REFS
AB - FLOW OSCILLATIONS ARE HIGHLY UNDESIRABLE AND MAY CAUSE FORCED MECHANICAL VIBRATION; THERMALLY INDUCED COMPONENTS AND SYSTEM CONTROL PROBLEMS. TWO-PHASE-FLOW THEPMALLY INDUCED INSTABILITIES ARE OF PARTICULAR INTEREST FOR NUCLEAR REACTORS. ON THE OTHER HAND, FLOW INSTABILITIES AFFECT LOCAL HEAT TRANSFER CHARACTERISTICS AND MAY INDUCE BOILING CRISES. A COMPARITIVE STUDY OF DIFFERENT STABILITY COMPUTER CODES REPORTED BY SAMI AND LE (1987) CONCLUDED THAT MUCH WORK IS STILL NEEDED IN ORDER TO ENHANCE THEIR RELIABILITY. THIS PAPER PRESENTS THE DEVELOPMENT OF A NUMERICAL MODEL DYNAM/US FOR PREDICTING THE DYNAMIC STABILITY OF BOILING CHANNELS.

22. TI - SHOCK PHENOMENA IN A ONE-COMPONENT TWO-PHASE BUBBLY FLOW.
AU - AKAGAWA; FUJII, T.; HIRAKI, S.; KITANO, T.; ITO, Y.; TSUBOKURA, S. (DEPT.OF MECHANICAL ENGINEERING, KOBE UNIV., NADA-KU, KOBE).
MERILO, M.
PU - P. 246-253. THERMAL HYDRAULICS OF NUCLEAR REACTORS. LAGRANGE PARK, IL (USA). AMERICAN NUCLEAR SOCIETY. 1983.
AB - CHARACTERISTICS OF SHOCK PHENOMENA INDUCED BY A QUICK VALUE CLOSURE AT THE DOWNSTREAM END OF A CHANNEL ARE INVESTIGATED. AN EXPERIMENT WAS CONDUCTED FOR A TWO-PHASE BUBBLY FLOW IN A HORIZONTAL STAINLESS TUBE OF 21.4 MM ID AND 16.17 M LENGTH, WITH A SURGE TANK HAVING A GAS CHAMBER AT THE UPSTREAM END. FREON 113 WAS USED AS THE WORKING FLUID. THE PRESSURE TRANSIENTS WERE MEASURED AT FOUR LOCATIONS ALONG THE TUBE. THE PROFILES OF THE TRANSIENT PRESSURE, THE POTENTIAL SURGE, THE EQUILIBRIUM PRESSURE RISE, AND THE PROPAGATION VELOCITY OF THE COMPRESSION WAVE ARE PRESENTED AND ARE DISCUSSED, COMPARING THEM WITH THOSE IN AN AIR-WATER TWO-COMPONENT TWO-PHASE FLOW.

23. TI - ANALYSIS OF WATER HAMMER OBSERVED IN FEEDWATER SYSTEMS OF CERTAIN PWR SYSTEMS.
AU - VREELAND, J.A. (CALIFORNIA STATE UNIV., SACRAMENTO).
PU - TRANS. AM. NUCL. SOC. (NOV 1975). V. 22 P. 540.

9.3 ELECTRIC POWER RESEARCH INSTITUTE

1. TI - DYNAMIC AND SEISMIC RELIABILITY OF NUCLEAR PIPING WITH WALL THINNING
AU - TECHNICAL INFORMATION DIVISION
CS - ELECTRIC POWER RESEARCH INSTITUTE
DA - START - 880712; COMPLETION - 880812; DATE OF UPDATE - 880727
NU - RP3010-01
AB - THE OBJECTIVE OF THIS PROJECT IS TO ESTABLISH AN EXPERIMENTAL DATABASE FOR THE ERODED/CORRODED PIPING TO QUANTIFY SEISMIC AND DYNAMIC MARGIN, TO INVESTIGATE DYNAMIC BEHAVIOUR AND FAILURE MODE, AND TO PROVIDE TECHNICAL BASIS IN SUPPORT OF PIPING INTEGRITY EVALUATION DUE TO EROSION AND CORROSION. SPECIFIC TASKS INCLUDE - (1) TEST PLANNING; (2) WATERHAMMER TESTS; (3) HYDRODYNAMIC TESTS; (4) SEISMIC TESTS; (5) STATIC LOAD TESTS; AND (6) DATA ACQUISITION, ANALYSIS, AND REPORTING.

2. TI - WATER HAMMER CONSULTING
AU - TECHNICAL INFORMATION DIVISION
CS - ELECTRIC POWER RESEARCH INSTITUTE (415)855-2411
DA - START - 871115; COMPLETION - 881231
CT - QUADREX CORPORATION
AB - QUADREX WILL PROVIDE CONSULTING TO EPRI'S PIPING RELIABILITY PROGRAM. TASKS INCLUDE - (1) EVALUATION OF WATER HAMMER TEST PLANS; AND (2) EVALUATION OF TEST RESULTS.

3. TI - WATER HAMMER PREVENTION, MITIGATION AND ACCOMMODATION
AU - TECHNICAL INFORMATION DIVISION
CS - ELECTRIC POWER RESEARCH INSTITUTE (415)855-2411
DA - START - 870820; COMPLETION - 870630; DATE OF UPDATE - 871211
NU - RP2856-03
AB - THE CONTRACTOR WILL CONDUCT A COMPREHENSIVE STUDY ON THE SUBJECT OF WATER HAMMER PREVENTION, MITIGATION, AND ACCOMMODATION. FOR PURPOSES OF THIS CONTRACT, TWO DEGREES OF WATER HAMMER ARE DEFINED - NORMAL AND SEVERE. EVENTS INVOLVING NORMAL WATER HAMMER (E.G. CONTROL VALVE CLOSURE AND FLASHING/COLLAPSING OVER A THROTTLED CONTROL VALVE) ARE THOSE EXPECTED TO OCCUR DURING VARIOUS SYSTEM OPERATION AND TRANSIENT CONDITIONS. NORMAL WATER HAMMER WILL GENERATE FORCES THAT POTENTIALLY CAN BE PREVENTED, MITIGATED, OR ACCOMMODATED BY DESIGN OR PROCEDURE, OR BOTH. EVENTS INVOLVING SEVERE WATER HAMMER (E.G. STEAM-BUBBLE COLLAPSE) ARE THOSE WHICH GENERATE FORCES WHICH CANNOT BE MITIGATED OR ACCOMMODATED AND THEREFORE MUST BE PREVENTED TO MAINTAIN THE INTEGRITY OF THE SYSTEM AND COMPONENTS. TASKS FOR THIS STUDY ARE TO - (1) COMPILE AND CLASSIFY PLANT WATER HAMMER EXPERIENCE; (2) PERFORM ROOT CAUSE ANALYSIS FOR WATER HAMMER; (3) COMPILE EXPERIMENTAL DATA ON WATER HAMMER; (4) REVIEW ANALYTICAL MODELS AND COMPUTER CODES; (5) DEVELOP GUIDELINES TO PREVENT, DIAGNOSE AND ASSESS WATER HAMMER FOR UTILITY ENGINEERS; (6) PERFORM IN-PLANT VERIFICATION; (7) REVIEW OF PLANT SPECIFIC OPERATING PROCEDURES AND DESIGNS; (8) DEVELOP TRAINING MODULES; AND (9) PREPARE TECHNOLOGY TRANSFER.

4. TI - WATER HAMMER DUE TO CHECK VALVE FAILURE
AU - TECHNICAL INFORMATION DIVISION
CS - ELECTRIC POWER RESEARCH INSTITUTE (415)855-2411
DA - START - 870801; COMPLETION - 891231
NU - RP2856-02
AB - THE OVERALL OBJECTIVE OF THIS WORK IS TO DEVELOP A THEORY THAT CAN BE USED TO DESCRIBE A WATER HAMMER. THEN, A MEANS FOR QUANTIFYING THE EFFECT OF CHANGES CAN BE DEVELOPED SO THAT THE MOST APPROPRIATE FIX FOR THE APPLICATION AT HAND CAN BE SELECTED. UNDER THIS CONTRACT THE FOLLOWING THREE PROBLEMS WILL BE INVESTIGATED - (1) REPRESSURIZATION-INDUCED WATER HAMMER; (2) WATER HAMMER DUE TO CONDENSATE TRAPPING; AND (3) VALVE DYNAMICS, WEAR, AND THE REQUIRED INSPECTION CYCLE.

5. TI - INVESTIGATION OF TURBULENT HEAT TRANSFER APPROACH FOR APPLICATIONS IN STEAM GENERATOR WATER HAMMER
AU - TECHNICAL INFORMATION DIVISION
CS - ELECTRIC POWER RESEARCH INSTITUTE (415)855-2411
DA - START - 870326; COMPLETION - 890601; DATE OF UPDATE - 870602
NU - RP2398-01
AB - THE GOALS OF THIS RESEARCH PROJECT ARE TO - (1) OBTAIN EXPERIMENTAL INFORMATION REGARDING THE HEAT TRANSFER RATE AND REYNOLDS STRESS TENSOR COMPONENTS IN, AND IN THE PROXIMITY OF, SINGLE-PHASE AND BOILING REGION OF FLOWS WITH HEAT ADDITION; (2) ENDEAVOUR TO CONCOCT CORRELATIONS ON THE BASIS OF THESE MEASUREMENTS FOR THE TURBULENT HEAT TRANSFER RATE AND SHEAR STRESS FOR USE IN TWO-FLUID MODEL OF SUCH FLOWS; AND (3) OBTAIN EXPERIMENTAL INFORMATION ON THE RELATION BETWEEN LOCAL VELOCITY FLUCTUATIONS AND WALL PRESSURE FLUCTUATIONS FRO SUCH FLOWS.

6. TI - WATER HAMMER PREVENTION, MITIGATION AND ACCOMMODATION
AU - TECHNICAL INFORMATION DIVISION
CS - ELECTRIC POWER RESEARCH INSTITUTE (415)855-2411
DA - START - 860301; COMPLETION - 901231; DATE OF UPDATE - 860702
NU - RP2856
AB - WATERHAMMER EVENTS IN NUCLEAR PLANTS OFTEN CAUSE PIPING DAMAGE AND PLANT OUTAGES. THE OBJECTIVES OF THIS PROJECT ARE TO - (1) INVESTIGATE THE PHYSICAL MECHANISMS OF THE WATER HAMMER PHENOMENA; (2) DEVELOP PROCEDURES TO PREVENT WATER HAMMER; (3) DEVELOP A SIMPLE METHODOLOGY TO PREDICT AND ANALYZE WATER HAMMER; AND (4) DOCUMENT THE RESULTS IN A HANDBOOK.

7. TI - WATER HAMMER STATUS UPDATE
AU - TECHNICAL INFORMATION UPDATE
CS - ELECTRIC POWER RESEARCH INSTITUTE (415)855-2411
DA - START - 860327; COMPLETION - 860930; DATE OF UPDATE - 860917
NU - RP2856-01
AB - THIS CONTRACT INVOLVED THREE MAIN TASKS. THE FIRST WAS TO REVIEW AND SUMMARIZE OBSERVATIONS AND CONCLUSIONS DEVELOPED FROM EVALUATION OF THE 150 WATER HAMMER TRANSIENTS WHICH OCCURRED BETWEEN 1969 AND1981 IN NUCLEAR POWER PLANTS. SECONDLY, THE LWR WATER HAMMER EVENTS WHICH HAVE OCCURRED FROM 1981 TO THE PRESENT WERE IDENTIFIED, TABULATED, AND CLASSIFIED. LER'S FORMED THE PRIMARY BASIS FOR

THIS EFFORT. FINALLY, THE EVENTS WHICH OCCURRED IN THE PAST FIVE YEARS WERE EVALUATED TO DETERMINE THEIR RELATION TO THE PREVIOUS EVENTS. THE FOCUS OF THIS TASK WAS TO ADDRESS THE QUESTIONS, "COULD THE RECENT EVENTS HAVE BEEN PREDICTED AND/OR PREVENTED BASED ON METHODS DEVELOPED IN PREVIOUS STUDIES?" AND "WHAT METHODS SHOULD BE FURTHER DEVELOPED TO FURTHER REDUCE THE FREQUENCY OF WATER/STEAM HAMMER EVENTS IN LWR'S?" EVALUATION ALSO FOCUSED ON METHODS SUITABLE FOR USE ON MICRO COMPUTERS AND ADDRESSED THE APPLICABILITY OF SYSTEMS CODES SUCH AS RETRAN, RELAP5 AND TRAC TO THE ANALYSIS OF WATER HAMMER TRANSIENTS.

8. TI - WORKSHOP ON PWR STEAM GENERATOR WATER HAMMER PROBLEMS
AU - TECHNICAL INFORMATION DIVISION
CS - ELECTRIC POWER RESEARCH INSTITUTE (415)855-2411
DA - START - 781024; COMPLETION - 790630; DATE OF UPDATE - 850517
NU - RP-WS78-132
AB - A WORKSHOP ON PRESSURIZED WATER REACTOR (PWR) STEAM GENERATOR WATER HAMMER PROBLEMS WAS HELD OCTOBER 24-25, 1982 IN PALO ALTO, CA. THIS WORKSHOP, INITIATED BY EPRI, WAS ATTENDED BY REPRESENTATIVES OF PWR OWNER UTILITIES, NUCLEAR STEAM SYSTEM SUPPLIERS, AND ARCHITECT-ENGINEER FIRMS. THE OBJECTIVE WAS TO REVIEW CURRENT STEAM GENERATOR WATERHAMMER PROBLEMS AND CONCERNS AND THE STATUS OF POTENTIAL SOLUTIONS TO THESE PROBLEMS, AND TO DEVELOP A CONSENSUS REGARDING WORK TO BE PURSUED IN THE FUTURE. A SUMMARY OF THE CURRENT STATUS OF STEAM GENERATOR WATERHAMMER PROBLEMS, RECOMMENDED FUTURE WORK, A COPY OF EACH PARTICIPANT'S PRESENTED MATERIAL, AND A COPY OF THE NRC PROGRAM FOR THE RESOLUTION OF GENERIC ISSUES RELATED TO NUCLEAR POWER PLANTS WATERHAMMER ACTIVITY ARE INCLUDED IN THE WORKSHOP PROCEEDINGS.

9. TI - REVIEW OF WATER HAMMER INCIDENTS IN BWR'S
AU - TECHNICAL INFORMATION DIVISION
CS - ELECTRIC POWER RESEARCH INSTITUTE (415)855-2411
DA - START - 810701; COMPLETION - 821231; DATE OF UPDATE - 840928
NU - RP-T118-14
AB - THIS PROJECT IS TO - (1) EXPAND THE WATER HAMMER LISTING TO COVER 1978-1980 USING THE EG&G LISTING FOR CASES PRIOR TO 1978; (2) BREAK BWR WATER HAMMER INCIDENTS DOWN BY SYSTEM; AND (3) CORRELATE WATER HAMMERS WITHIN BWR SYSTEMS WITH INCIDENTS OF PIPE CRACKING (IGSCC, ETC.) REPORTED IN THESE SYSTEMS.

10. TI - EXAMINATION OF THE TMI-2 SNUBBERS - PHASE 2
CS - ISSUED BY - ELECTR. POWER RES. INST., PALO ALTO, CA, USA
PU - 15 AUG. 1984; 92P. AVAIL - RES. REP. CENTER, BOS 50490, PALO ALTO, CA, USA
NU - EPRI-NP-3593
AB - LARGE NUMBERS OF MECHANICAL SNUBBERS, DESIGNED TO PROTECT NUCLEAR POWER PLANT PIPING FROM SEISMIC LOADS, MAY NOT BE NEEDED ON SMALL PIPES. THIS STUDY OF SNUBBERS AT THREE MILE ISLAND SHOWS THAT, DESPITE SNUBBER FAILURE EITHER BEFORE OR DURING THE ACCIDENT, PLANT PIPING REMAINED UNDAMAGED. THE DAMAGE TO THE SNUBBERS IS THOUGHT TO HAVE BEEN CAUSED BY WATER HAMMER DURING THE ACCIDENT.

11. TI - WORKSHOP PROCEEDINGS: FLOW-INDUCED VIBRATIONS.
AU - HETSRONI, G.; STEININGER, D. A.
CS - ELECTRIC POWER RESEARCH INST., PALO ALTO, CA.
PU - NOV 78; 213P; WORKSHOP ON FLOW-INDUCED VIBRATIONS, PALO ALTO, CA, USA, 21 AUG 1978; PC A10/MF A01
NU - REPT. CONF-780880

12. TI - PIPING VIBRATION FROM TWO-PHASE STEAM WATER FLOW
AU - TECHNICAL INFORMATION DIVISION
CS - ELECTRIC POWER RESEARCH INSTITUTE
(415) 855-2411
DA - START: 860829; COMPLETION: 881231
NU - RP2290-07

13. TI - WATER IMPACT TESTS OF BWR PRESSURE SUPPRESSION SYSTEM MODELS
AU - TECHNICAL INFORMATION DIVISION
CS - ELECTRIC POWER RESEARCH INSTITUTE
(415) 855-2411
DA - START: 760730; COMPLETION: 781231; DATE OF UPDATE: 840928
NU - RP0817-01

14. TI - COMMENTS ON STEAM GENERATOR WATER HAMMER PROGRAM. (PWR.)
AU - BANKOFF, S.G.
GREEN, S.J.; WELTY, C.S. JR.
OR - ELECTRIC POWER RESEARCH INST., PALO ALTO, CA (USA). 9500767
PU - P. 13.1-13.20. WORKSHOP PROCEEDINGS: STEAM GENERATOR WATERHAMMER. JUN 1979.

15. TI - SUMMARY OF CURRENT WORK. (PWR.)
AU - MARTIN, C.S.
GREEN, S.J.; WELTY, C.S. JR.
OR - ELECTRIC POWER RESEARCH INST., PALO ALTO, CA (USA). 9500767
PU - P. 12.1-12.3. WORKSHOP PROCEEDINGS: STEAM GENERATOR WATERHAMMER. JUN 1979.

16. TI - OBSERVATIONS ON STEAM GENERATOR WATER HAMMER. (PWR.)
AU - HILDEBRANDT, P.C. (DUKE POWER CO., CHARLOTTE, NC).
GREEN, S.J.; WELTY, C.S. JR.
OR - ELECTRIC POWER RESEARCH INST., PALO ALTO, CA (USA). 9500767
PU - P. 11.1-11.5. WORKSHOP PROCEEDINGS: STEAM GENERATOR WATERHAMMER. JUN 1979.

17. TI - FLUID TRANSIENT ANALYSIS AND DESIGN CONSIDERATIONS IN TVA PWR FEEDWATER SYSTEMS AND STEAM GENERATORS.
AU - KELLEY, B.T.
GREEN, S.J.; WELTY, C.S. JR.
OR - ELECTRIC POWER RESEARCH INST., PALO ALTO, CA (USA). 9500767
PU - P. 10.1-10.21. WORKSHOP PROCEEDINGS: STEAM GENERATOR WATERHAMMER. JUN 1979.

18. TI - BECHTEL ONGOING WORK ON WATERHAMMER.
AU - MCBRIDE, J.
GREEN, S.J.; WELTY, C.S. JR.
OR - ELECTRIC POWER RESEARCH INST., PALO ALTO, CA (USA). 9500767
PU - P. 8.1-8.8. WORKSHOP PROCEEDINGS: STEAM GENERATOR WATERHAMMER. JUN 1979.

19. TI - WATER HAMMER DESIGN CONSIDERATIONS.
AU - MITLO, T.J.
GREEN, S.J.; WELTY, C.S. JR.
OR - ELECTRIC POWER RESEARCH INST., PALO ALTO, CA (USA). 9500767
PU - P. 7.1-7.14. WORKSHOP PROCEEDINGS: STEAM GENERATOR WATERHAMMER. JUN 1979.

20. TI - INVESTIGATION OF BUBBLE COLLAPSE WATER HAMMER IN SPLIT FLOW PREHEAT STEAM GENERATORS.
AU - RUMANCIK, J.A.; CERMAK, J.O. (WESTINGHOUSE ELECTRIC CORP., PITTSBURGH, PA). GREEN, S.J.; WELTY, C.S. JR.
OR - ELECTRIC POWER RESEARCH INST., PALO ALTO, CA (USA). 9500767
PU - P. 6.1-6.24. WORKSHOP PROCEEDINGS: STEAM GENERATOR WATERHAMMER. JUN 1979.

21. TI - INVESTIGATION OF CONDENSATION INDUCED WATERHAMMER IN CE STEAM GENERATORS.
AU - SINGH, B.K. (COMBUSTION ENGINEERING, INC., CHATTANOOGA, TN).
GREEN, S.J.; WELTY, C.S. JR.
OR - ELECTRIC POWER RESEARCH INST., PALO ALTO, CA (USA). 9500767
PU - P. 5.1-5.15. WORKSHOP PROCEEDINGS: STEAM GENERATOR WATERHAMMER. JUN 1979.

22. TI - WATERHAMMER IN STEAM GENERATORS AND OTHER RELATED SYSTEMS.
AU - SINGH, G. (COMBUSTION ENGINEERING, WINDSOR, CT).
GREEN, S.J.; WELTY, C.S. JR.
OR - ELECTRIC POWER RESEARCH INST., PALO ALTO, CA (USA). 9500767
PU - P. 4.1-4.35. WORKSHOP PROCEEDINGS: STEAM GENERATOR WATERHAMMER. JUN 1979.

23. TI - WATERHAMMER CONSIDERATIONS IN ONCE THROUGH STEAM GENERATORS.
AU - SHERBURNE, P.A.; RUSH, G.C. GREEN, S.J.; WELTY, C.S. JR.
OR - ELECTRIC POWER RESEARCH INST., PALO ALTO, CA (USA). 9500767
PU - P. 3.1-3.19. WORKSHOP PROCEEDINGS: STEAM GENERATOR WATERHAMMER. JUN 1979.

24. TI - WATERHAMMER IN STEAM GENERATORS AND FEEDWATER PIPING.
AU - MARTIN, C.S. (GEORGIA INST. OF TECHNOLOGY, ATLANTA).
GREEN, S.J.; WELTY, C.S. JR.
OR - ELECTRIC POWER RESEARCH INST., PALO ALTO, CA (USA). 9500767
PU - P. 1.1-1.46. WORKSHOP PROCEEDINGS: STEAM GENERATOR WATERHAMMER. JUN 1979.

25. TI - WORKSHOP PROCEEDINGS: STEAM GENERATOR WATERHAMMER.
AU - GREEN, S.J.; WELTY, C.S. JR.
OR - ELECTRIC POWER RESEARCH INST., PALO ALTO, CA (USA). 9500767
PU - JUN 1979. 272 P.

26. TI - UNDERSTANDING FEEDWATER LINE PRESSURE SURGES.
AU - HOWARD, N.M.; GREEN, S.J.; WELTY, C.S. JR.
OR - ELECTRIC POWER RESEARCH INST., PALO ALTO, CA (USA). 9500767
PU - P. 9.1-9.16. WORKSHOP PROCEEDINGS: STEAM GENERATOR WATERHAMMER. JUN 1979.

27. TI - BRIEF LITERATURE REVIEW PERTINENT TO STEAM GENERATOR WATER HAMMER.
AU - BANKOFF, S.G. (NORTHWESTERN UNIV., EVANSTON, IL).
GREEN, S.J.; WELTY, C.S. JR.
OR - ELECTRIC POWER RESEARCH INST., PALO ALTO, CA (USA). 9500767
PU - P. 2.1-2.13. WORKSHOP PROCEEDINGS: STEAM GENERATOR WATERHAMMER. JUN 1979.

9.4 AMERICAN SOCIETY OF MECHANICAL ENGINEERS

1. TI - WATERHAMMER IN U.S. NUCLEAR POWER PLANTS
   AU - SERKIZ, A.W.
   PU - AMERICAN SOCIETY OF MECHANICAL ENGINEERS (PAPER) PUBLISHED BY ASME, N.Y., N.Y., 1987
   AB - THE LINCREASE IN WATERHAMMER IN U.S. NUCLEAR POWER PLANTS IN THE MID-1970'S LED THE U.S. NUCLEAR REGULATORY COMMISSION (NRC) TO DESIGNATE WATERHAMMER (WH) AS AN UNRESOLVED SAFETY ISSUE (USI) IN 1978. CORRECTIVE ACTIONS THAT WERE RELATED TO BOTH DESIGN AND PLANT OPERATIONS WERE IMPLEMENTED BY THE INDUSTRY. AFTER DESIGNATING WH AS A USI, THE NRC EVALUATED WH OCCURRENCES, UNDERLYING CAUSES, SEVERITY OF DAMAGE, AND THE LIKE, AND CONCLUDED IN 1983 THAT WH WAS NOT AS SIGNIFICANT A SAFETY THREAT AS PREVIOUSLY POSTULATED. HOWEVER, THE WH AT THE SAN ONOFRE PLANT IN NOVEMBER 1985 LED THE NRC TO REEXAMINE WH EVENTS FROM 1981 THROUGH 1985. THIS PAPER DISCUSSES THE FINDINGS FROM THAT REVIEW, WHICH ALSO REVEAL THAT (1) TOTAL ELIMINATION OF WH IS NOT POSSIBLE, (2) PROPER DESIGN AND OPERATIONAL PRECAUTIONS CAN BE TAKEN TO REDUCE THE FREQUENCY AND SEVERITY OF WH, AND (3) THE MOST SEVERE WHS HAVE OCCURRED IN FEEDWATER SYSTEMS AS A RESULT OF WATER SLUGS INDUCED BY STEAM CONDENSATION. (AUTHOR ABSTRACT)

2. TI - NON-INTUITIVE FLUID DYNAMICS FROM REACTOR AND CONTAINMENT TECHNOLOGY
   AU - MOODY, F.J.
   PU - AMERICAN SOCIETY OF MECHANICAL ENGINEERS, FLUIDS ENGINEERING DIVISION (PUBLICATION) FED V 39. PUBLISHED BY ASME, NEW YORK, N.Y., U.S.A. P 19-21, 1986
   AB - ONE EXCITING ASPECT OF FLUID DYNAMICS IS THAT THE SUBJECT HAS MANY SURPRISES. THE SURPRISES CAN BE GOOD, BUT IF NOT ANTICIPATED, THEY SOMETIMES CAN BE COSTLY AND EMBARRASSING. SEVERAL NON-INTUITIVE FLUID RESPONSES HAVE EMERGED FROM STUDIES IN NUCLEAR REACTOR AND CONTAINMENT DESIGN. THESE RESPONSES INCLUDE BUBBLE BEHAVIOR, BLOWDOWN, AND WATERHAMMER PHENOMENA. SEVERAL NON-INTUITIVE FLUID DYNAMICS PROBLEMS HAVE BEEN DISCUSSED, WHICH LEND A CERTAIN FASCINATION TO THE CRAFT. THESE AND MANY OTHER PROBLEMS WHICH CONTAIN UNEXPECTED BEHARIOR OFTEN CAN BE PREDICTED BY SIMPLE ANALYSES. FINDING SUCH SURPROSES ON PAPER OR IN THE LAB CAN PREVENT COSTLY REDESIGN OF FLUID SYSTEMS. (EDITED AUTHOR ABSTRACT)

3. TI - TRANSIENT PRESSURE (WATERHAMMER) LOADS IN CANDU EMERGENCY COOLANT INJECTION (ECI) SYSTEM
   AU - GOEL, M.L.; FRANCISCO, J.M.
   PU - AMERICAN SOCIETY OF MECHANICAL ENGINEERS, FLUIDS ENGINEERING DIVISION (PUBLICATION) FED V 41, PUBLISHED BY ASME, NEW YORK, N.Y., U.S.A. P 19-27, 1986
   AB - WATERHAMMER TRANSIENT LOADINGS ARE MAJOR CONSIDERATIONS IN THE CANDU ECI SYSTEM DESIGN. THE PRESSURE TRANSIENT BEHAVIOUR IS PREDICTED USING A COMPUTER PROGRAM PTRAN. PTRAN PREDICTIONS OF PEAK AND DIFFERENTIAL PRESSURE TRANSIENTS ARE COMPARED WITH THE WATERHAMMER COMMISSIONING TESTS CARRIED OUT ON THE BRUCE 'B' ECI SYSTEM, WHICH IS A HIGH PRESSURE LIQUID/GAS SYSTEM. (AUTHOR ABSTRACT)

4. TI - MULTIDIMENSIONAL WATERHAMMER ANALYSIS USING A NODE-FLOW LINK APPROACH
AU - SCHWIRIAN, R.E.
PU - AMERICAN SOCIETY OF MECHANICAL ENGINEERS, FLUIDS ENGINEERING DIVISION (PUBLICATION) FED V 30, PUBLISHED BY ASME, NEW YORK, N.Y., U.S.A. P 69-77, 1985
AB - A NODE FLOW LINK METHODOLOGY FOR ANALYZING MULTIDIMENSIONAL WATERHAMMER TYPE LOADS IN FLUID SYSTEMS IS PRESENTED. THE METHOD IS SHOWN TO BE ADAPTABLE TO WAVE PROPAGATON ANALYSES IN BOTH ONE DIMENSIONAL REGIONS LIKE PIPING SYSTEMS, OR LARGER MULTIDIMENSIONAL REGIONS LIKE PLENA, OR BOTH. A SAMPLE PROVLEM IS PRESENTED IN WHICH THE AZIMUTHAL AND RADIAL PRESSURE GRADIENT-TIME HISTORIES IN A CYLINDRICAL PLENUM RESULTING FROM A BREAK IN THE PIPING CONNECTED TO IT ARE INVESTIGATED. (EDITED AUTHOR ABSTRACT)

5. TI - FLUID- STRUCTURE INTERACTION IN WATERHAMMER RESPONSE OF FLEXIBLE PIPING
AU - BELYTSCHKO, T.; KARABIN, M.; LIN, J.I.
PU - AMERICAN SOCIETY OF MECHANICAL ENGINEERS, PRESSURE VESSELS AND PIPING DIVISION (PUBLICATION) PVP V 86, PUBLISHED BY ASME, NEW YORK, N.Y., U.S.A. P 127-142, 1984
AB - IN THE WATERHAMMER ANALYSIS OF PIPING SYSTEMS, INCOMPRESSIBLE (OR ADDED MASS) REPRESENTATIONS ARE GENERALLY USED IN COMPUTING THE RESPONSE OF THE PIPING. IT IS SHOWN THAT THIS PROCEDURE IS NOT NECESSARILY CONSERVATIVE, PARTICULARLY FOR THIN-WALLED, FLEXIBLE PIPING SYSTEMS, AND THAT FULLY COUPLED FLUID-STRUCTURE SOLUTIONS CAN PREDICT HIGHER LOADS AND STRESSES. A MODAL RECOVERY PROCEDURE WHICH EASILY PERMITS THE REPRESENTATION OF THE ACOUSTIC EFFECTS OF THE FLUID TO BE INCLUDED IN A STRAUCTURAL MODEL IS ALSO PRESENTED. RESULTS ARE GIVEN FOR BOTHE SIMPLE MODELS AND A PIPING SYSTEM FROM AN LMFBR DESIGN.

6. TI - DESIGN OF ELEVATED TRMPERATURE PIPING
AU - MALLETT, R.H. (ED.); MELLO, R.M. (ED.)
PU - AMERICAN SOCIETY OF MECHANICAL ENGINEERS, PRESSURE VESSELS AND PIPING DIVISION (PUBLICATION) PVP V 86, PUBLISHED BY ASME, NEW YORK, N.Y., U.S.A. 155P, 1984
AB - THIS CONFERENCE PROCEEDINGS CONTAINS 11 PAPERS EVALUATING DIFFERENT ASPECTS OF THE STRUCTURAL DESIGN OF ELEVATED TEMPERATURE, THIN-WALLED PIPING SUCH AS USED IN LIQUID METAL FAST BREEDER NUCLEAR REACTORS (LMFBR). RESULTS ARE PRESENTED OF WATERHAMMER ANALYSIS, SEISMIC RESPONSE ANALYSIS, AND DAMPING IN LMFBR PIPING SYSTEMS. A SURVEY IS PRESENTED OF COLD SPRINGING OF PIPING METHODS AND APPROACHES USED IN THE POWER INDUSTRY AND THEIR APPLICABILITY TO LMFBR PIPING. THE QUESTION OF ELASTIC FOLLO-UP IN THIN-WALLED PIPING IS EXAMINED.

7. TI - METHOD FOR WATERHAMMER ANALYSIS OF CONTROL ROD DRIVE PIPING
AU - MOK, G.C.
PU - AMERICAN SOCIETY OF MECHANICAL ENGINEERS, PRESSURE VESSELS AND PIPING DIVISION (PUBLICATION) PVP V 91, PUBLISHED BY ASME, NEW YORK, N.Y., U.S.A. P 1-7, 1984
AB - THIS PAPER PRESENTS AN EXPERIMENTALLY-VALIDATED COMPUTATIONAL METHOD FOR HYDRAULIC TRANSIENT ANALYSIS. USING THE METHOD AND A

HYPOTHETICAL SYSTEM. A STUDY IS MADE OF THE WATERHAMMER PHENIMENON IN THE CONTROL ROD DRIVE (CRD) PIPING OF A BOILING WATER REACTOR (BWR). SPECIFICALLY, THE INFLUENCE OF VARIOUS DESIGN AND OPERATION VARIABLES ON THE MAGNITUDE OF THE LOADS IS INVESTIGATED. IT IS SHOWN THAT TWO WATERHAMMER EVENTS EXIST, EACH OF WHICH IS GOVERNED BY A DIFFERENT MECHANISM. AMONG ALL THE PARAMETERS CONSIDERED, THE PIPE FRICTION HAS THE LEAST INFLUENCE, WHEREAS THE CONDITIONS OF THE SCRAM VALVE AND OF THE CRD BUFFER HAVE THE MOST DIRECT AND DOMINANT EFFECTS ON THE LOADS.

8. TI - TWO-PHASE FLOW AND WATERHAMMER LOADS IN VESSELS, PIPING, AND STRUCTURAL SYSTEMS, PRESENTED AT THE ASME 1984 PRESSURE VESSEL AND PIPING CONFERENCE AND EXHIBITION
AU - MOODY, F.J. (ED.); SHUI, Y.W. (ED.)
PU - ASME PRESSURE VESSELS PIPING DIVISION (PUBLICATION) PVP V 91, TWO-PHASE FLOW AND WATERHAMMER LOACS IN VESSELS, PIPING AND STRUCTURAL SYSTEM, SAN ANTONIO, TX. U.S.A., JUNE 17-21, 1984, 102P.
AB - THIS CONFERENCE PROCEEDINGS CONTAINS 9 PAPERS WHICH ADDRESS RECENT ADVANCES IN THE PREDICTION OF FLUID FORCING FUNCTIONS. THE ANALYSIS TECHNIQUES ARE PARTICULARLY RELEVANT TO NUCLEAR POWER PLANT FLOW PHENOMENA. WATERHAMMER ANALYSIS, TWO PHASE JET FLOW, IMPACT LOADS AND THERMAL STRESS CALCULATIONS ARE ALSO DISCUSSED. TECHNICAL AND PROFESSIONAL PAPERS FROM THIS CONFERENCE ARE INDEXED AND ABSTRACTED WITH THE CONFERENCE CODE NO. 04394 IN THE EI ENGINEERING MEETINGS (TM) DATABASE PRODUCED BY ENGINEERING INFORMATION, INC.

9. TI - WATERHAMMER IN THE FEEDWATER SYSTEMS OF PWR STEAM GENERATORS
AU - ROTHE, PAUL H.; WALLIS, GRAHAM B.; CROWLY, CHRISTOPHER J.
PU - FLUID TRANSIENTS AND ACCOUST IN THE POWER IND., PRESENTED AT ASME WINTER ANNUAL MEETING, SAN FRANCISCO, CALIF., DEC 10-15, 1978, PUBLISHED BY ASME, N.Y., N.Y., 1978, P 75-85

10. TI - NUCLEAR PLANT WATER-HAMMER CURRENT STATUS
AU - UFFER, ROY
PU - AMERICAN SOCIETY OF MECHANICAL ENGINEERS (PAPER) PUBLISHED BY ASME, NEW YORK, N.Y., U.S.A. PAP 87- PVP- 17, 1987
AB - WATER HAMMER HAS BEEN RESOLVED BY THE USNRC AS A SAFETY ISSUE WITH THE CONCLUSIONS THAT WATER HAMMER DOES NOT PRESENT A SIGNIFICANT RISK TO PUBLIC SAFETY AND THAT DESIGN AND OPERATIONAL MODIFICATIONS HAVE REDUCED THE FREQUENCY OF WATER HAMMER EVENTS. WATER HAMMERS STILL OCCUR AT AN APPROXIMATELY CONSTANT LOW RATE AND PRESENT AN EXONOMIC RATHER THAN A SAFETY CONCERN. NUCLEAR POWER PLANT WATER HAMMERS ARE PRIMARILY CAUSED BY LINE VOIDING, STEAM BUBBLE COLLAPSE, CONTROL VALVE INSTABILITIES AND WATER ENTRAINMENT IN STEAM LINES. (AUTHOR ABSTRACT)

11. TI - INTEGRITY ISSUES IN PWR STEAM GENERATORS AND FEEDWATER SYSTEMS
AU - BAMFORD, W.H.; SMITH, L.C.; THURMAN, A.L.
PU - AMERICAN SOCIETY OF MECHANICAL ENGINEERS, PRESSURE VESSELS AND PIPING DIVISION (PUBLICATION) PVP V 119, PUBLISHED BY ASME, NEW YORK, N.Y., U.S.A. P 19-29, 1987
AB - PRESSURIZED WATER REACTORS HAVE NOW BEEN OPERATING COMMERCIALLY FOR OVER TWENTY-FIVE YEARS, AND DURING THIS TIME MUCH HAS BEEN LEARNED ABOUT ESTABLISHING AND MAINTAINING RELIABLE OPERATION. THIS PAPER

WILL DISCUSS THREE OPERATIONAL ISSUES WHICH HAVE OCCURRED IN THE STEAM GENERATOR PRESSURE BOUNDARY, AND DISCUSS THE IMPROVEMENTS WHICH WERE DEVELOPED TO HELP PROTECT AGAINST FUTURE OCCURRENCE. THE ISSUES ARE FEEDWATER LINE CRACKING, GIRTHWELD CRACKING OF THE STEAM GENERATOR SHELL, AND WATER HAMMER. (EDITED AUTHOR ABSTRACT)

12. TI - TWO-PHASE WATER HAMMER IN NUCLEAR POWER PLANTS
AU - KIM, J.H.
PU - AMERICAN SOCIETY OF MECHANICAL ENGINEERS, FLUIDS ENGINEERING DIVISION (PUBLICATION) FED V 50, PUBLISHED BY ASME, NEW YORK, N.Y., U.S.A. P 117-120, 1987
AB - THE NUMBER OF WATER HAMMER EVENTS IN NUCLEAR POWER PLANTS DECLINED OVER THE PAST, BUT STILL KEEP OCCURRING AT UNACCEPTABLY HIGH FREQUENCY. WATER HAMMER CAUSES DAMAGES TO PLANT EQUIPMENT AND CHALLENGES INTEGRITY OF THE PLANT COMPONENTS AND SYSTEM. ALTHOUGH NOT CONSIDERED A SERIOUS SAFETY RISK, ECONOMIC LOSSES DUE TO WATER HAMMER ARE SIGNIFICANT. WATER HAMMER CANNOT BE COMPLETELY ELIMINATED. ITS FREQUENCY OF OCCURRENCE SHOULD, HOWEVER, BE FURTHER REDUCED. TWO-PHASE WATER HAMMER PHENOMENA ARE NOT FULLY UNDERSTOOD BECAUSE OF SO MANY PARAMETERS INVOLVED, SUCH AS THERMAL-HYDRAULIC CONDITIONS OF BOTH PHASES, THEIR COMPLICATED INTERACTION SUCH AS CONDENSATION, AND GEOMETRIC CONFIGURATIONS. A COHERENT INDUSTRIAL PROGRAM IS CURRENTLY BEING DEVELOPED THAT ADDRESSES R&D NEEDS RANTGING FROM STUDY OF THE FUNDAMENTAL MECHANISM TO DEVELOPMENT OF PRACTICAL PRODUCT.

13. TI - DEVELOPMENT OF RESEARCH ON WATER HAMMER PHENOMENA IN TWO-PHASE FLOW -PROGRESS IN OUR RESEARCH UNIT AT KOBE UNIVERSITY
AU - AKAGAWA, K.; FUJII, T.
PU - V 5, PUBLISHED BY ASME, NEW YORK, N.Y., U.S.A. P 333-349, 1987 PROCEEDINGS OF THE 1987 ASME-JSME THERMAL ENGINEERING JIONT CONFERENCE, HONOLULU, HI, U.S.A., MARCH 22-27, 1987
AB - WATER HAMMER PHENOMENA CAUSED BY RAPID VALVE CLOSURE, THAT IS, SHOCK PHONOMENA IN TWO-PHASE FLOWS ARE AN IMPORTANT PROBLEM FOR THE SAFETY ASSESSMENT OF A HYPOTHETICAL LOCA. THIS PAPER PRESENTS A REVIEW OF EXPERIMENTAL AND ANALYTICAL STUDIES ON THE WATER HAMMER PHENOMENA WHICH HAVE BEEN CONDUCTED IN OUR RESEARCH UNIT AT KOBE UNIVERSITY SINE 1977 AND ALSO PRESENTS THE BASIC CONCEPT IN CARRYING OUT THESE EXPERIMENTS. IN ORDER TO CLARIFY THE CHARACTERISTICS OF SHOCK PHENOMENA, VARIOUS ANALYTICAL METHODS AND EXPERIMENTS WERE CONDUCTED - I) EXPERIMENTS FOR A TWO-PHASE AIR-WATER FLOW AND A ONE-COMPONENT TWO-PHASE FLOW OF FREON R-113, II) A THEORETICAL ANALYSIS OF THE MAGNITUDE OF PRESSURE RISES, III) A NUMERICAL SIMULATION OF PRESSURE TRANSIENTS TO OBTAIN SOLUTIONS EXPRESSED IN ANALYTICAL FORM. AS A RESULT, AN OVERALL PICTURE OF THE WATER HAMMER PHENOMENA IS PRESENTED AND DISCUSSED. (AUTHOR ABSTRACT)

14. TI - FORUM ON UNSTEADY FLOW - 1986
AU - ROTHE, PAUL H. (ED.)
PU - AMERICAN SOCIETY OF MECHANICAL ENGINEERS, FLUIDS ENGINEERING DIVISION (PUBLICATION) FED V 39, PUBLISHED BY ASME, NEW YORK, N.Y., U.S.A., 1986
AB - THIS CONFERENCE PROCEEDINGS CONTAINS 18 PAPERS PRESENTING THE CURRENT STATUS OF RESEARCH PROJECTS IN UNSTEADY FLOW. THE

PROCEEDINGS ARE ARRANGED INTO THREE MAIN SESSIONS - UNSTEADY FLOW IN PIPELINES, UNSTEADY FLOW IN COMPONENTS AND APPLICATIONS, AND BASIC STUDIES OF UNSTEADY FLOW. FAST FOURIER TRANSFROM TECHNIQUES ARE PRESENTED FOR THE COMPUTATION OF HYDRAULIC SYSTEM TRANSIENTS. A HEURISTIC NUMERICAL STUDYIS PROVIDED OF DIRECT AIR JET IMPINGEMENT OF HIGH HEAT FLUX ELECTRONIC COMPONENTS. A NUMERICAL SIMULATION IS ALSO PRESENTED OF A PRESSURIZED WATER NUCLEAR REACTOR COOLANT PUMPS ON AND OFF. LAMINAR UNSTEADY FLOW IN PIPES AND A REVIEW OF CURRENT TRENDS IN FLUID TRANSMISSION LINE DYNAMIC REPRESENTATIONS ARE ALSO INCLUDED.

15. TI - CRITIQUE OF HYDRAULIC TRANSIENT SIMULATION IN COOLING WATER SYSTEMS
AU - MARTIN, C.S.; WIGGERT, D.C.
PU - AMERICAN SOCIETY OF MECHANICAL ENGINEERS, FLUIDS ENGINEERING DIVISION (PUBLICATION) FED V 41, PUBLISHED BY ASME, N.Y., N.Y., U.S.A. P 29-40, 1986
AB - THIS PAPER ILLUSTRATES THE APPLICATION OF A STANDARD WATERHAMMER PROGRAM BY MODIFYING THE CODE TO ALLOW FOR THE FREE AIR IN A LUMPED MODE. SPECIAL CONSIDERATION WAS ALSO GIVEN TO THE TREATMENT OF THE CONDENSER AND THE WATER LEVEL IN THE DOWNSTREAM WATER BOX. FOR THREE SYSTEMS FOR WHICH SITE MEASUREMENTS WERE AVAILABLE, COMPARISONS BETWEEN THEORY AND EXPERIMENT ARE MADE. AFTER MANY COMPUTER TRIALS AND CODE MODIFICATIONS GOOD AGREEMENT BETWEEN MEASUREMENT AND THEORY WAS ACHIEVED. (AUTHOR ABSTRACT)

16. TI - ASME PRESSURE VESSELS AND PIPING CONFERENCE
AU - ANON
PU - AMERICAN SOCIETY OF MECHANICAL ENGINEERS (PAPER) PUBLISHED BY ASME, N.Y., N.Y., U.S.A., 1986
AB - THIS CONFERENCE PRCEEDINGS CONTAINS 16 PAPERS. SOME OF THE TOPICS DISCUSSED ARE POWER PLANT COMPONENT WEAR; STEAM GENERATOR TUBE FRETTING; FATIGUE WEAR; HEAT EXCHANGER WEAR; PIPING SYSTEM CORROSION; AND NUCLEAR REACTOR COMPONENT CORROSION. OTHER TOPICS COVERED ARE PRESSURE VESSEL RELIABILITY; WATER HAMMERS; SAFETY DESIGN FACTORS; RAILROAD TANK CAR DESIGN; CAR FIRE PROTECTION; AND HAZARDOUS MATERIALS TRANSPORTATION.

17. TI - PLANT AVAILABILITY IMPROVEMENT BY ELIMINATION OF WATER HAMMER
AU - CHIU, CHONG; REILLY, JAMES T.
PU - AMERICAN SOCIETY OF MECHANICAL ENGINEERS (PAPER) PUBLISHED BY ASME, N.Y., N.Y., U.S.A., 10P, 1986
AB - WATER HAMMER OCCURS VERY OFTEN AT A POWER PLANT. IT CAN BE GENERALLY CATEGORIZED INTO THREE TYPES, I.E., VALVE CLOSURE (OR OPENING) INDUCED, WATER SLUG INDUCED, AND CONDENSATION INDUCED WATER HAMMER. THIS PAPER REVIEWS THE BASIC PHENOMENA OF WATER HAMMER AND THEIR THEORETICAL FORMULATIONS. THREE RECENT REAL-LIFE EXAMPLES (EACH DEVOTED TO ONE TYPE OF WATER HAMMER) WHICH HAVE CAUSED CONSIDERABLE PLANT EQUIPMENT DAMAGE ARE DELINEATED. THE MAGNITUDES OF THE PRESSURE WAVE GENERATED BY THE WATER HAMMERS HAVE BEEN DERIVED BASED ON THE SEVERITY OF THE ENSUING PIPE SUPPORT DAMAGE. THEY ARE FAVORABLY COMPARED WITH THE THEORETICAL PREDICTION. ALSO, METHODS TO ELIMINATE EACH TYPE OF WATER HAMMER ARE DESCRIBED IN THIS PAPER. (EDITED AUTHOR ABSTRACT)

18. TI - COLUMN SEPARATION AND REJOINING FIELD STUDY
AU - YOW, WUSHUNG; VAN DUYNE, DANIEL A.; BUDLONG, LINWOOD A.; QUINLAN, PETER J.
PU - AMERICAN SOCIETY OF MECHANICAL ENGINEERS, FLUIDS ENGINEERING DIVISION (PUBLICATION) FED V 27, PUBLISHED BY ASME, N.Y., N.Y., U.S.A. P 18-20, 1985
AB - THE RESULTS, WITH THE AIR VENT LINE INSTALLED AT THE INLET TO THE HVK, INDICATED THAT COLUMN SEPARATION AND REJOINING EFFECTS WERE VISIBLY AND AUDIBLY UNDETECTABLE. THE AIR INLET LINE CAUSED THE COLUMN SEPARATION TO OCCUR VERY QUICKLY FOLLOWING SWP PUMP TRIP, BUT COMUMN REJOINING WAS CUSHIONED BY THE ENTRAPPED AIR THAT COMPRESSED WITHOUT SIGNIFIACNT PEAK PRESSURE BUILDUP. THE FOLLOWING CONCLUSIONS MAY BE DRAWN FROM THSES SWP WATERHAMMER TRANSIENT TESTS - 1. A VAPOR GAP WAS FORMED IN THE RELATIVELY HIGH ELEVATION PIPING NEAR THE HVK AFTER THE SWP PUMP TRIPPED, 2. WITH THE ORIGINAL SYSTEM DESIGN, CLOSURE OF THE GAP NEAR THE HVK PRODUDED SIGNIFICANT PEAK PRESSURES AND POTENTIALLY SEVERE TRANSIENT FORCES WITH THE MOV-102 VALVE OPEN LARGER THAN 20 PERCENT, 3. THE ADDITION OF A SMALL AIR VENT LINE ON THE INLET PIPING TO THE HVK MITIGATED THE POTENTIALLY SIGNIFICANT GAP CLOWURE TRANSIENTS.

19. TI - WATER HAMMER ANALYSIS NEEDS IN NUCLEAR POWER PLANT DESIGN
AU - UFFER, ROY A.
PU - AMERICAN SOCIETY OF MECHANICAL ENGINEERS, FLUIDS ENGINEERING DIVISION (PUBLICATION) FED V 27, PUBLISHED BY ASME, N.Y., N.Y., U.S.A. P 16-27, 1985
AB - THE OCCURRENCE OF WATER HAMMER EVENTS IN NUCLEAR POWER PLANTS, THE IDENTIFICATION OF WATER HAMMER AS THE USNRC'S UNRESOLVED SAFETY ISSUE (USI) A-1 AND THE SUBSEQUENT RESOLUTION OF USI A-1 HAS LED TO CONSIDERABLE RESEARCH IN WATER HAMMER ANALYSIS METHODOLOGY. DURING AND AFTER THE RESOLUTION OF USI A-1, NUMEROUS QUESTIONS HAVE BEEN RAISED REGARDING AREAS IN WHICH FURTHER WATER HAMMER ANALYTICAL DEVELOPMENT WOULD BE OF BENEFIT TO THE NUCLEAR POWER INDUSTRY. THIS PAPER WILL IDENTIFY SOME OF THE AREAS WHERE THE RESULTS OF SUCH DEVELOPMENT WOULD OR WOULD NOT BE UTILIZED IN NUCLEAR POWER PLANT DESIGN.

20. TI - FORUM ON UNSTEADY FLOW - 1985
AU - ROTHE, PAUL H. (ED.)
PU - ASME, FLUIDS ENGINEERING DIVISION (PUBLICATION) FED V 27, PUBLISHED BY ASME, N.Y., N.Y., U.S.A. 1985
AB - THIS BOOKLET PRESENTS A FORUM ON UNSTEADY FLOW SPONSORED BY THE FLUID TRANSIENTS COMMITTEE OF THE FLUIDS ENGINEERING DIVISION OF ASME AND CONTAIN 14 PAPERS. THE PAPERS IN THE BOOKLET IS IN THE BROAD TOPIC OF UNSTEADY FLOW. THE PAPERS PRESENTS UNSTEADY FLOW IN PIPES, JETS, BOUDARY LAYER, WAVES AND FLOW INTERACTIONS. MATHEMATICAL MODELS ARE USED TO ANALYZE THE FLOWS. NUCLEAR POWER PLANT DESIGN AND OPERATION IN CONNECTION WITH UNSTEADY FLOW AND WATERHAMMER ARE DEALT WITH IN THSES PAPERS. TWO DIMENSIONAL FLOWS, PRESSURE TRANSIENTS IN BOREHOLES DUE TO PIPE MOVEMENT AND TAIL PROFILE EFECTS ON UNSTEADY LARGE SCALE FLOW STRUCTURE IN THE WING AND PLAT FUNCTION ARE SOME OF THE TOPICS DEALT IN THIS FORUM.

21. TI - FLUID TRANSIENTS IN FLUID-STRUCTURE INTERACTION - 1985
AU - DODGE, F.T.(ED.); MOODY, F.J. (ED.)
PU - ASME, FLUIDS ENGINEERING DIVISION (PUBLICATION) FED V 30, N.Y., N.Y., U.S.A. 122P, 1985
AB - THIS CONFERENCE PROCEEDINGS CONTAIN 16 PAPERS. VARIOUS ASPECTS OF THE FLOW OF FLUIDS AND FLUID-STRUCTURE INTERACTIONS ARE COVERED. THE TOPICS INCLUDE SPACECRAFT FUEL SLOSHING, PIPE FLUID FLOW, STEAM TURBINE FLUID DYNAMICS, WATER HAMMER, NUCLEAR REACTOR SHUTDOWN, LOSS OF COOLANT ACCIDENTS, REACTOR CONTAINMENT, STEAM CONDENSATION, AND PIPING SYSTEMS. OTHER TOPICS COVER MATHEMATICAL TECHNIQUES AND COMPUTER SIMULATIONS.

22. TI - CALCULATION OF WATER HAMMER LOAC CONSIDERING TWO-DIMENSIONAL EFFECTS
AU - CHANG, F.H.; HANCOCK, S.; MENTLEY, J.
PU - ASME, FLUID ENGINEERING DIVISION, FED V 18, N.Y., N.Y., U.S.A. P 17-21, 1984
AB - THIS PAPER EXAMINES THE NEED TO CONSIDER TWO-DIMENSIONAL EFFECTS IN A SEVERE WATER HAMMER TRANSIENT. WATER HAMMER INVOLVING THE FLOW OF A SLUG OF WATER IN S- AND U-SHAPED PIPESECTIONS IS COMPUTED USING BOTH ONE- AND TWO-DIMENSIONAL MODELS. THE TWO-DIMENSIONAL CALCULATIONS SHOW A STRONG TENDENCY FOR THE FLOW TO STRATIFY. IN THE TWO-DIMENSIONAL U-SHAPED CALCULATION, THE WATER SLUG IS COMPLETELY BROKEN UP, AND THE RESULTING PIPE IS 100P LESS THAN IN THE ONE-DIMENSIONAL CASE. (AUTHOR ABSTRACT)

23. TI - WATER HAMMER LOADS IN BWR CONTROL ROD DRIVE SYSTEMS
AU - SAFWAT, H.H.; ARASTU, A.H.
PU - ASME, FLUID ENGINEERING DIVISION (PUBLICATION) FED V15, N.Y., N.Y., U.S.A. P 13-17, 1984
AB - THIS PAPER DISCUSSES THE CALCULATION OF NET UNBALANCED FLUID FORCE TIME HISTORY DUE TO PRESSURE WAVE TRAVEL ON A PIPE SEGMENT BETWEEN TWO ELBOWS. GENERALLY, THE SUPPORT STRUCTURE DESIGN FOR WATER HAMMER LOADING MAKES USE OF THESE FORCING FUNCTIONS IN A DYNAMIC STRUCTURAL ANALYSIS. PRESENTED IN THIS PAPER ARE THE RESULTS OF A SENSITIVITY STUDY ON FORCING FUNCTIONS DUE TO CHANGES IN THE CRD SCRAM VALVE OPENING TIMES, PIPING OVERALL LENGTH, CRD PISTON INITIAL POSITION (STROKE, RESISTANCE OF THE HYDRAULIC BUFFER HOLES AND REACTOR CONDITIONS (START UP OR NORMAL OPERATING).

24. TI - CALCULATION OF WATER HAMMER LOAD RESULTING FROM RAPID STEAM BUBBLE CONDENSATION
AU - ATTIA, A.V.; RUHL, S.F.
PU - ASME, PRESSURE VESSELS AND PIPING DIVISION (PUBLICATION) PVP V 91, N.Y., N.Y., U.S.A. P 57-62, 1984
AB - IN LWR PLANTS, RAPID CONDENSATION OCCURS WHEN STEAM IS SUDDENLY EXPOSED TO SUBCOOLED WATER. THIS RAPID COLLAPSE OF THE STEAM REGION CAUSES WATER TO ACCELERATE AND IMPACT SURROUNDING STRUCTURES AT HICH VELOCITIES. WE CONSIDER ONLY THE LOCAL PHENOMENON OF STEAM REGION COLLAPSE, WATER SLUG ACCELERATION, AND WATER SLUG IMPACT INSIDE A RIGID PIPE CLOSED END. WE PRESENT A CALCULATION, USING THE PISCES COMPUTER CODE, TO OBTAIN AN UPPER BOUND ON THE WATERHAMMER LOAD THAT WAS OBTAINED IN THE CREARE WATER CANNON EXPERIMENTS. RESULTS SHOW EFFECT OF STEAM CONDENSATION AND FRICTION.

25. TI - WATER HAMMER IN NUCLEAR POWER PLANTS
AU - UFFER, R.
PU - ASME, PRESSURE VESSELS AND PIPING DIVISION (PUBLICATION) PVP V 74, N.Y., N.Y., U.S.A. P 55-61, 1983

26. TI - PRESSURE VESSELS AND PIPING CONFERENCE
AU - ANON
PU - ASME (PAPER) PUBLISHED BY ASME, N.Y., N.Y., U.S.A., 1983

27. TI - WATER HAMMER IN NUCLEAR POWER PLANT WITH TILTING-DISC CHECK VALVE.
AU - PHAM, LONG KIM
PU - ASME (PAPER) PUBLISHED BY ASME, NY, NY, USA, PVP 34, 1983.

28. TI - METHODS FOR SIMULATING FLUID-STRUCTURE INTERACTION AND CAVITATION WITH EXISTING FINITE ELEMENT FORMULATIONS
AU - SCHWIRIAN, R.E.
PU - ASME, PRESSURE VESSELS AND PIPING DIVISION (PUBLICATION) PVP V 64, N.Y.,N.Y., U.S.A. P 261-285, 1982

29. TI - REASSESSMENT OF PWR PRESSURE-VESSEL INTEGRITY DURING OVERCOOLING ACCIDENTS
AU - CHEVERTON, R.D.; BALL, D.G.
PU - ASME, PRESSURE VESSELS AND PIPING CONFERENCE, PORTLAND, OREGON, U.S.A., 29P, 19 JUNE 1983

30. TI - ON SOME ASPECTS OF STEAM BUBBLE COLLAPSE
AU - CHO, S.M.; SEBAN, R.A.
PU - TRANS. ASME (USA), SERIES C
NOV. 1969 ; 91(4); 537-42

31. TI - REVIEW OF FLOW-INDUCED VIBRATION IN TWO-PHASE FLOW.
AU - CHEN, S. S.
PU - AMERICAN SOCIETY OF MECHANICAL ENGINEERS, FLUIDS ENGINEERING DIVISION (PUBLICATION) FED V 63. PUBL BY ASME (PVP V 131), NEW YORK, NY, USA P 1-4, 1987; 45 REFS.

32. TI - MODAL SUPERPOSITION TRANSIENT ANALYSIS VERIFICATION FOR MARK I SUPPRESSION CHAMBERS.
AU - ADAMS, R. H.; KUMAR, V.
PU - PUBL BY ASME, NEW YORK, NY, USA P 505-518, 1984

33. TI - SOURCE AND LOADING CONDITIONS IN PRESSURE SUPPRESSION SYSTEMS - RESULTS OF THE MULTIVENT LARGE SCALE PRESSURE SUPPRESSION EXPERIMENTS.
AU - AUST, E.; BOETTCHER, G.; KOLB, M.; VOLLBRANDT, J.; MCCAULEY, E. W.; HOLMAN, G. S.
PU - TRANSACTIONS OF THE INTERNATIONAL CONFERENCE ON STRUCTURAL MECHANICS IN REACTOR TECHNOLOGY 6TH. PUBL BY NORTH-HOLLAND PUBL CO, AMSTERDAM, NETH, FOR COMM OF THE EUR COMMUNITIES (EUR7146), BRUSSELS, BELG. DISTRIB IN USA AND CAN BY ELSEVIER NORTH-HOLLAND, NEW YORK, NY, USA J 2. 10, 11 P, 1981

34. TI - ADMISSIBLE BLOWDOWN LOADING FOR SPHERICAL CONTAINMENTS WITH PRESSURE SUPPRESSION SYSTEM.

AU - KRIEG, R.; GOELLER, B.; HAILFINGER, G.
PU - TRANSACTIONS OF THE INTERNATIONAL CONFERENCE ON STRUCTURAL MECHANICS IN REACTOR TECHNOLOGY 6TH. PUBL BY NORTH-HOLLAND PUBL CO, AMSTERDAM, NETH, FOR COMM OF THE EUR COMMUNITIES (EUR7146), BRUSSELS, BELG. DISTRIB IN USA AND CAN BY ELSEVIER NORTH-HOLLAND, NEW YORK, NY, USA J 2. 4, 10 P, 1981

35. TI - EXPERIMENTAL DETERMINATION OF SINGLE AND TWO-PHASE CROSS FLOW-INDUCED FORCES ON TUBE ROWS.
AU - TAYLOR, C.E.; PETTIGREW, M.J.; AXISA, F.; VILLARD, B.
PU - J PRESSURE VESSEL TECHNOL TRANS ASME V 110 N 1 FEV 1988 P 22-28; 10 REFS

36. TI - SECOND-ORDER ACCURATE EXPLICIT FINITE-DIFFERENCE SCHEMES FOR WATERHAMMER ANALYSIS
AU - CHAUDHRY, M.H.; HUSSAINI, M.Y.
PU - TRANS. ASME. J. FLUIDS ENG. (USA)
DEC. 1985 ; 107(4); P. 523-9 ; 8 REFS

37. TI - STABILITY OF STEAM-WATER COUNTERCURRENT FLOW IN AN INCLINED CHANNEL. II. CONDENSATION-INDUCED WATERHAMMER
AU - LEE, S.C.; BANKOFF, S.G.
PU - TRANS. ASME. J. HEAT TRANSFER (USA)
NOV. 1984 ; 106(4); P. 900-2 ; 13 REFS

38. TI - VALVE STROKING TO CONTROL WATERHAMMER TRANSIENTS USING DYNAMIC PROGRAMMING
AU - CONTRACTOR, D.N.; MARTIN, C.S.; CHAUDHRY, M.H.
PU - NUMERICAL METHODS FOR FLUID TRANSIENT ANALYSIS. APPLIED MECHANICS, BIOENGINEERING, AND FLUIDS ENGINEERING CONFERENCE
Publ: NEW YORK, USA ; ASME
1983 ; P. 77-81 ; V+81 P.; 6 REFS

39. TI - RADIAL AND AXIAL VARIATIONS IN TRANSIENT PRESSURE WAVES TRANSMITTED THROUGH LIQUID TRANSMISSION LINES
AU - MITRA, A.K.; ROULEAU, W.T.; MARTIN, C.S.; CHAUDHRY, M.H.
PU - NUMERICAL METHODS FOR FLUID TRANSIENT ANALYSIS. APPLIED MECHANICS, BIOENGINEERING, AND FLUIDS ENGINEERING CONFERENCE
Publ: NEW YORK, USA ; ASME
1983 ; P. 39-46 ; V+81 P.; 8 REFS

40. TI - SECOND-ORDER EXPLICIT FINITE-DIFFERENCE METHODS FOR TRANSIENT-FLOW ANALYSIS
AU - CHAUDHRY, M.H.; MARTIN, C.S.
PU - NUMERICAL METHODS FOR FLUID TRANSIENT ANALYSIS. APPLIED MECHANICS, BIOENGINEERING, AND FLUIDS ENGINEERING CONFERENCE
Publ: NEW YORK, USA ; ASME
1983 ; P. 9-15 ; V+81 P.; 11 REFS

41. TI - PULSE PROPAGATION IN FLUID-FILLED TUBES
AU - WALKER, J.S.; PHILLIPS, J.W.
PU - TRANS. ASME SER. E (USA)
MARCH 1977 ; 44(1); 31-5

42. TI - PERTURBATION SOLUTIONS FOR STEADY ONE-DIMENSIONAL WATERHAMMER WAVES
AU - WALKER, J.S.
PU - TRANS. ASME SER. I (USA)
JUNE 1975 ; 97(2); 260-2

43. TI - METHODOLOGY FOR QUANTITATIVE ASSESSMENT OF THE IMPACT OF SAFETY FACTORS ON STRUCTURAL INTEGRITY.
AU - JOURIS, G. M.; SHAFFER, D. H.
CS - WESTINGHOUSE RES LAB, PITTSBURGH, PA
PU - STRUCT INTEGRITY TECHNOL, PAP PRESENTED AT A CONF, WASHINGTON, DC, MAY 9-11 1979 PUBL BY ASME, NEW YORK, NY, 1979 P 45-47

44. TI - FIRST INTERNATIONAL MULTIPHASE FLUID TRANSIENTS SYMPOSIUM.
AU - SAFWAT, H.H.; BRAUN, J.; ROHATGI, U.S.
PU - NEW YORK, NY (USA). AMERICAN SOCIETY OF MECHANICAL ENGINEERS. 1986. 101 P. FED-VOLUME 41.
AB - THIS BOOK PRESENTS THE PAPERS GIVEN AT A CONFERENCE ON MULTIPHASE FLOW. TOPICS CONSIDERED AT THE CONFERENCE INCLUDED TRANSIENT PRESSURE (WATERHAMMER) LOADS IN CANDU EMERGENCY COOLANT INJECTION SYSTEMS, TRANSIENT AND MULTICOMPONENT FLOWS THROUGH PACKED BEDS, AND NOISE TRANSFER FUNCTIONS FOR TWO FLUID FLOW.

45. TI - AN ANALYSIS OF WATER HAMMER PHENOMENA IN BUBBLY FLOWS.
AU - FUJII, T.; AKAGAWA, K. (DEPT. OF MECHANICAL ENGINEERING, FACULTY OF ENGINEERING, KOBE UNIV., KOBE). MICHAELIDES, E.E.
PU - P. 147-154. FUNDAMENTAL ASPECTS OF GAS-LIQUID FLOWS. NEW YORK, NY (USA). AMERICAN SOCIETY OF MECHANICAL ENGINEERS. 1985.
AB - WATER HAMMER PHENOMENA CAUSED BY A SUDDEN VALVE CLOSURE ARE CONSIDERED IN BOTH TWO-COMPONENT AND ONE-COMPONENT TWO-PHASE FLOWS. BASIC PARTIAL DIFFERENTIAL EQUATIONS BASED ON A ONE-DIMENSIONAL HOMOGENEOUS FLOW MODEL ARE SOLVED ANALYTICALLY BE LAPLACE TRANSFORMATION REPEATED TWICE, ONCE WITH RESPECT TO TIME AND THEN WITH RESPECT TO DISTANCE. THE PROFILES OF THE PRESSURE TRANSIENTS, AND THE EFFECTS OF VALVE CLOSING TIME AND FRICTION LOSS ON TRANSIENT PRESSURES ARE OBTAINED. IN PARTICULAR, IT IS SHOWN THAT THE MASS TRANSFER BETWEEN THE TWO PHASES HAS GREAT INFLUENCE ON THE PROFILE OF THE PRESSURE TRANSIENTS IN ONE-COMPONENT TWO-PHASE FLOWS AND THAT THE MAGNITUDE OF THE INFLUENCE DEPENDS ON THE RELAXATION TIME T/SUB M/ OF THE INTERPHASE MASS TRANSFER.

46. TI - FUNDAMENTAL ASPECTS OF GAS-LIQUID FLOWS.
AU - MICHAELIDES, E.E.
PU - NEW YORK, NY (USA). AMERICAN SOCIETY OF MECHANICAL ENGINEERS. 1985. 183 P.
AB - THIS BOOK PRESENTS THE PAPERS GIVEN AT A CONFERENCE ON TWO-PHASE FLOW. TOPICS CONSIDERED AT THE CONFERENCE INCLUDED THE THERMAL HYDRAULICS OF A FEEDWATER PIPE BREAKAGE, PRESSURE LOSSES, MEASUREMENT OF VOID FRACTION IN A ROD BUNDLE, LAMINAR FILMWISE CONDENSATION, NATURAL CIRCULATION, FLOW MODELS, BUBBLE DYNAMICS, CAVITATION, WATER HAMMER, AND HEAT TRANSFER AUGMENTATION.

47. TI - THERMAL HYDRAULICS OF A FEED-WATER PIPE BREAKAGE WITH A BACK-PRESSURE CHECK VALVE.
AU - TRAVIS, J.R.; TORRAY, M.D. (THEORETICAL DIV., GROUP T-3, UNIV. OF

CALIFORNIA). MICHAELIDES, E.E.
PU - P. 1-9. FUNDAMENTAL ASPECTS OF GAS-LIQUID FLOWS. NEW YORK, NY (USA). AMERICAN SOCIETY OF MECHANICAL ENGINEERS. 1985.
AB - THE SOLA-LOOP COMPUTER CODE FOR TRANSIENT, NON-EQUILIBRIUM, TWO-PHASE FLOWS IN NETWORKS HAS BEEN COUPLED WITH A DYNAMIC CHECK VALVE MODEL. TRANSIENT BACK-PRESSURE CHECK VALVE BEHAVIOUR AND FLUID DYNAMIC EFFECTS IN THE FORM OF THE SO CALLED WATER-HAMMER ARE NUMERICALLY SIMULATED FOR A FEED-WATER PIPE BREAKAGE ACCIDENT. THREE TESTS FROM THE SUPERHEATED STEAM REACTOR SAFETY PROGRAM PROJECT (PHDR) CARRIED OUT NEAR FRANKFURT, WEST GERMANY ARE ANALYZED, AND THE BEHAVIOUR AND FLUID DYNAMICS EFFECTS ARE FOUND TO BE IN EXCELLENT AGREEMENT WITH THE EXPERIMENTALLY MEASURED DATA.

48. TI - EVALUATION OF MAIN FEEDWATER LINE INSTABILITY DUE TO THE SUDDEN OPENING OF FLOW CONTROL VALVE.
AU - KATHIRESAN, R.M.; HUANG, S.M.; TONET, N. (SCHNEIDER CONSULTING ENGINEERS, PITTSBURGH, PA).
PU - AM. SOC. MECH. ENG., (PAP.). (NOV 1983). V. 83-WA/NE-6 P. 5.
AB - FEEDWATER PIPING IN A NUCLEAR POWER PLANT CAN BE SUBJECTED TO TRANSIENT FORCES DUE TO THE SUDDEN OPENING OF FLOW CONTROL VALVES. A NUMERICAL ANALYSIS OF THE VALVE TRANSIENT PROBLEM IS PERFORMED TO SIMULATE AN INCIDENT THAT OCCURRED AT AN OPERATING FACILITY. THE RESULTS OF THE INVESTIGATION OF HYDRODYNAMIC LOADS ON THE FEEDWATER AFOREMENTIONED EVENT ARE PRESENTED. THE COMPUTER CODE WAVENET IS EMPLOYED TO CALCULATE THE FLUID TRANSIENT RESPONSE AND HYDRODYNAMIC LOADS. THE NUPIPE FINITE ELEMENT COMPUTER PROGRAM IS USED TO CALCULATE THE STRUCTURAL RESPONSE OF THE FEEDWATER PIPING AND PIPING SUPPORT FOR THESE TRANSIENT HYDRODYNAMIC LOADS. BASED ON THE ANALYSIS, POTENTIAL PROBLEM AREAS IN THE FEEDWATER PIPELINE IN TERMS OF BOTH SUPPORT LOADS AND STRESSES ARE INDENTIFIED. THE RESULTS OBTAINED SUCCESSFULLY VERIFY THE MATHEMATICAL MODELING PROCEDURE OF THE FAILURE OF THE PIPE SUPPORTS AND SNUBBERS.

49. TI - WATER HAMMERS IN DIRECT CONTACT HEATER SYSTEMS.
AU - UFFER, R. (QUADREX CORPORATION, CAMPBELL, CA).
PU - AM. SOC. MECH. ENG., PRESSURE VESSELS PIPING DIV., (TECH. REP.) PVP. (1983). (PVP-VOL. 74) P. 41-46.

50. TI - COLD LEG ECC FLOW OSCILLATIONS.
AU - ROTHE, P.H.; WALLIS, G.B.; BLOCK, J.A. (CREARE INC., HANOVER, NH). JONES, O.C. JR.; BANKOFF, S.G. (EDS.).
PU - P. 133-150. THERMAL AND HYDRAULIC ASPECTS OF NUCLEAR REACTOR SAFETY. VOL. I. NEW YORK. AMERICAN SOCIETY OF MECHANICAL ENGINEERS. 1977.

51. TI - ANALYSIS OF WATERHAMMER LOADS IN A TYPICAL NUCLEAR PIPING SYSTEM.
AU - HARPER, C.R.; HSIEH, J.S.; LUK, C.H. (STONE AND WEBSTER ENG CORP, BOSTON, MASS).
PU - AM. SOC. MECH. ENG., (PAP.). (1975). (75-PVP-53) P. 1-8.

52. TI - EFFECTS OF THE STEAM CHEST ON STEAMHAMMER ANALYSIS FOR NUCLEAR PIPING SYSTEMS.
AU - LUK, C. (STONE AND WEBSTER ENG CORP, BOSTON, MASS).
PU - AM. SOC. MECH. ENG., (PAP.). (1975). (75-PVP-61) P. VP.

9.5 MISCELLANEOUS (UNIVERSITIES, JOURNALS, ETC.)

1. TI - INVESTIGATION OF THE STEAM VOID COLLAPSE WATERHAMMER INITIATING MECHANISM
AU - DEMMIE, P.N.
CS - IDAHO NATIONAL ENGINEERING LAB, IDAHO FALLS, USA
PU - FEB 79; 32P;PC A03/MF A01
AB - A INVESTIGATION OF THE STEAM VOID COLLAPSE WATERHAMMER INITIATING MECHANISM WAS MADE. THE RESULTS AND CONCLUSIONS OF THIS INVESTIGATION ARE PRESENTED AND DISCUSSED. (ERA CITATION 05 -003070)

2. TI - WORKSHOP PROCEEDINGS - STEAM GENERATOR WATERHAMMER
AU - GREEN, S.J.; WELTY, C.S. JR.
CS - ELECTRIC POWER RESEARCH INST., PALO ALTO, CA.; 062881000 9500767
PU - JUN 79; 272P; WORKSHOP ON STEAM GENERATOR WATERHAMMER, PALO ALTO, CA, USA, 24 OCT 1978; PC A12/MF A01
AB - THE PROCEEDINGS OF A WORKSHOP ON PRESSURIZED WATER REACTOR (PWR) STEAM GENERATOR WATERHAMMER PROBLEMS IS PRESENTED. THIS WORKSHOP, INITIATED BY THE ELECTRIC POWER RESEARCH INSTITUTE (EPRI) WAS ATTENDED BY REPRESENTATIVES OF PWR OWNER UTILITIES, NUCLEAR STEAM SYSTEM SUPPLIERS, AND ARCHITECT-ENGINEER FIRMS. THE OBJECTIVE OF THE WORKSHOP WAS TO REVIEW CURRENT STEAM GENERATOR WATERHAMMER PROBLEMS AND CONCERNS AND THE STATUS OF POTENTIAL SOLUTIONS TO THESE PROBLEMS, AND TO DEVELOP A CONSENSUS REGARDING WORK TO BE PURSUED IN THE FUTURE. A SUMMARY OF THE CURRENT STATUS OF STEAM GENERATOR WATERHAMMER PROBLEMS, RECOMMENDED FUTURE WORK, A COPY OF EACH PARTICIPANT'S PRESENTED MATERIAL, AND A COPY OF THE NRC PROGRAM FOR THE RESOLUTION OF GENERIC ISSUES RELATED TO NUCLEAR POWER PLANTS WATERHAMMER ACTIVITY ARE INCLUDED. (ERA CITATION 07 -007233)

3. TI - EXISTENCE OF A GLOBAL WEAK SOLUTION TO THE NONLINEAR WATERHAMMER PROGRAM
AU - LUSKIN, M.; TEMPLE, B.
CS - NEW YORK UNIVERSITY, NY, USA
PU - DEC 81; 60P; PORTIONS OF DOCUMENT ARE ILLEGIBLE; PC A04/MF A01
AB - THE EXISTENCE OF GLOBAL WEAK SOLUTIONS TO AN INITIAL - BOUNDARY VALUE PROBLEM FOR A NONLINEAR HYPERBOLIC SYSTEM WHICH MODELS FLUID FLOW IN PIPE IS PROVEN. THE EFFECT OF FRICTION IS MODELED BY A QUADRATIC A ZERO ORDER TERM TO THE SYSTEM OF CONSERVATION LAWS FOR COMPRESSIBLE, FRICTIONLESS FLOW. A PRIORI BOUNDS ARE OBTAINED BY MEANS OF A NON-INCREASING FUNCTIONAL THAT IS COMPATIBLE WITH THE FRICTION EFFECTS. THE BOUNDARY VALUES FOR THIS PROBLEM CANNOT BE IMPOSED WEAKLY, SO NEW RESULTS ON THE REGULARITY OF THE SOLUTION AT THE BOUNDARY ARE GIVEN. (ERA CITATION 07 -044401)

4. TI - HYDRAULIC TRANSIENT PRESSURES IN PIPING
AU - HUANG, CHARLES C.; BRADSHAW, RICHARD J. JR
CS - ARMY ENGINEERING DIVISION, HUNTSVILLE, ALABAMA
PU - 1974; 16P

5. TI - INFLUENCE OF LINE MOTION ON WATERHAMMER PRESSURES
AU - WOOD, DON J.; ASCE, M.
PU - 1969; 21P; AVAILABILITY - PUB. IN JNL. OF THE HYDRAULICS DIV., PROCEEDINGS OF THE AMERICAN SOCIETY OF CIVIL ENGINEERS, HY-3 N6572 P941-959 MAY 69

6. TI - HYDROELASTIC PHENOMENA IN BOILING WATER REACTOR SUPPRESSION POOLS
AU - NICHOLS, B.D.; HIRT, C.W.
PU - 1979; 8P; INTERNATIONAL CONFERENCE ON STRUCTURAL MECHANICS IN REACTOR TECHNOLOGY, BERLIN, F.R. GERMANY, 13 AUG 1979; PC A02/MF A01

7. TI - DESIGN FOR WATERHAMMER IN PLANT SERVICE-WATER SYSTEMS
AU - YOW, W.; VAN DUYNE, D.A.
PU - POWER V 131 N 7 JUL 1987 P 45-46
AB - HYDRAULIC TRANSIENTS IN PIPING SYSTEMS RESULT FROM RAPID CHANGES IN OPERATIONAL FUNCTIONING OF COMPONENTS, SUCH AS PUMPS AND VALVES. LARGE MOMENTUM CHANGES CAN SUBJECT SYSTEM COMPONENTS TO SEVERE FORCE TRANSIENTS, AND THESE MUST BE CONSIDERED WHEN DESIGNING THE SYSTEM TO ENSURE ITS SAFE, RELIABLE OPERATION. ALLOWING FOR TRANSIENTS AT THE DESIGN STAGE NOT ONLY PRECLUDES FAILURE OF PIPING SYSTEMS, BUT ALSO OPERATING PROCEDURES. TRANSIENTS THAT EXHIBIT SINGLE-PHASE FLOW CAN BE ANALYZED BY ONE-DIMENSIONAL WAVE THEORY. DURING A TRANSIENT CONDITION, PRESSURE WAVES MAY BE ANALYZED WITH THE AID OF A COMPUTER. AN EXAMPLE OF APPLICATION OF THE COMPUTER PROGRAM TO THE SERVICES-WATER SYSTEM OF A NUCLEAR POWER PLANT IS PRESENTED. VARIOUS DEVICES THAT MAY BE USED TO PROTECT PIPING SYSTEMS FROM DAMAGE BY SEVERE HYDRAULIC TRANSIENTS ARE BRIEFLY DESCRIBED.

8. TI - WATERHAMMER IN A PRIMARY COOLANT SYSTEM BY CONTROLLING A CIRCULATING PUMP REVOLUTION
AU - KATO, EIJI; SUITA, MINORU; KAWAMATA, MASAAKI; OHMORI, SHINICHI
PU - NIPPON KIKAI GAKKAI RONBUNSHU B HEN V 50 N 458 OCT 1984 P 2625-2630; 14 REFS.
AB - STUDIES HAVE BEEN MADE TO COMPARE AND DISCUSS THE ANALYTICAL SOLUTIONS SOLVED BY THE METHOD OF CHARACTERISTICS WITH THE EXPERIMENTAL RESULTS OF THE WATERHAMMER. THE MEASUREMENTS HAVE BEEN CARRIED OUT USING THE 1/6 SCALE MODEL OF THE PRIMARY COOLANT SYSTEM OF THE EXPERIMENTAL FAST BREEDER REACTOR 'JOYO' BELONGING TO THE POWER REACTOR AND NUCLEAR FUEL DEVELOPMENT CORPORATION. THE WATERHAMMER HAS BEEN TAKEN PLACE AT THE VALVE THROAT AREA RATIO RANGING FROM 1/4 TO 4/4 BY VARYING IN CIRCULATING PUMP REVOLVING SPEED IN THE ANGULAR ACCELERATION RANGES 20 TO 180 RAD/S**2 AND -20 TO -180 RAD/S**2. GOOD AGREEMENT WAS FOUND BETWEEN THE ANALYTICAL RESULTS AND EXPERIMENTAL. THEREFORE THE CALCULATION MODELS AND IDEA USED IN THIS PAPER HAVE SUFFICIENT PRACTICAL VALUE. (AUTHOR ABSTRACT) IN JAPANESE.

9. TI - WATERHAMMER IN A PRIMARY COOLANT SYSTEM BY CONTROLLING A CIRCULATING PUMP REVOLUTION
AU - KATO, EIZI; SUITA, MINORU; KAWAMATA, MASAAKI; OHMORI, SHINITI
PU - BULL JSME V 28 N 240 JUN 1985 P 1085-1091; 14 REFS.
AB - THE PRESENT PAPER DESCRIBES AN ANALYSIS BY THE METHOD OF CHARACTERISTICS CONSIDERING THE PUMP CHARACTERISTIC, LOSSES SUCH AS VALVE AND FLUID FRICTION, INERTIA OF THE PUMP AND PRESSURE VESSELS

TO DETERMINE THE PRESSURE OF A WATERHAMMER GENERATED BY RAPIDLY ACCELERATING AND DECELERATING THE CIRCULATION PUMP IN A CIRCULATING PIPELINE WITH PRESSURE VESSELS. THE VALIDITY OF APPLYING THE METHOD TO THE PHENOMENON IS INVESTIGATED WITH AN OBSERVATION SHOWING GOOD AGREEMENT BETWEEN ANALYTICAL AND EXPERIMENTAL RESULTS.

10. TI - STRESSES CAUSED BY WATERHAMMER LOADS IN A FEEDWATER PIPING SYSTEM - RESULTS OF TESTS AND PRACTICAL APPLICATIONS / BEANSPRUCHUNG EINER SPEISEWASSERLEITUNG DURCH DRUCKSTOSSBELASTUNG - VERSUCHSERGERNISSE UND PRAKTISCHE ANWENDUNGEN.
AU - HABIP, L. MORIS
PU - SIEMENS FORSCH ENTWICKLUNGSBER V 12 N 6 1983 P 386-394
AB - IN THE COURSE OF BLOWDOWN TESTS WITH A CHECK VALVE AT THE HEISSDAMPFREAKTOR KARLSTEIN, THE STRUCTURAL RESPONSE OF A FEEDWATER PIPING SYSTEM SUBJECTED TO WATERHAMMER LOADS HAS BEEN INVESTIGATED. A SIMPLE THEORETICAL FORMULA IS PRESENTED BY MEANS OF WHICH MAXIMUM DYNAMIC STRAINS IN THE PLASTIC RANGE, AT LOCATIONS WHERE CONVENTIONAL STRESS LIMITS ARE CONSIDERABLY EXCEEDED, CAN BE CALCULATED ON THE BASIS OF AN ELASTIC ANALYSIS ONLY. EXPERIMENTAL RESULTS CONFIRMED THIS APPROACH. THE PIPING SURVIVED SUCH OVERLOADS WITHOUT THE USE OF SNUBBERS. FURTHERMORE, THE RANGE OF VALIDITY OF THE NEW FORMULA IS INVESTIGATED FOR A NONLINEAR OSCILLATOR SUBJECTED TO A SINGLE PULSE. IN GERMAN.

11. TI - WATER HAMMER PREVENTION, MITIGATION AND ACCOMMODATION
CS - STONE & WEBSTER ENGINEERING CORPORATION
DA - DATE OF UPDATE - 871211
NU - RP2856-01; S&W

12. TI - WATER HAMMER IN NUCLEAR SYSTEMS
AU - MULCAHY, MICHAEL J.
CS - MANAGER, RESEARCH BOSTON EDISON CO. (617)424-3392
DA - COMPLETION - 830430; DATE OF UPDATE - 850906
NU - BECO RD-086
AB - WATER HAMMER IS PRODUCED BY COLLAPSE OF STEAM BUBBLES IN PIPES AND WATER HAMMER INCIDENTS IN CONVENTIONAL AND NUCLEAR STEAM SYSTEMS CONSTITUTE AN IMPORTANT PROBLEM OF BROAD GENERAL INTEREST IN PIPING NETWORK DESIGN AND TRANSIENT OPERATION. ACCORDINGLY, BOSTON EDISON COMPANY (BECO), NUSCO, AND CONSUMER POWER COMPANY JOINTLY FUNDED AN EXPERIMENTAL AND ANALYTICAL UTILITY PROGRAM (ELEUP). THE OVERALL GOAL OF THE PROJECT WAS (BY THE ANALYTICAL AND EXPERIMENTAL WORK) TO OBTAIN A BETTER UNDERSTANDING OF THE PHENOMENON, TO OBTAIN REALISTIC ESTIMATES OF WATER HAMMER LOADS AND, THUS, TO IMPROVE PROCEDURES FOR PIPING SYSTEM DESIGN (FOR NUCLEAR AND OTHER PLANTS) AND PREVENT PIPE DAMAGE FROM WATER HAMMER INCIDENTS.

13. TI - THERMIT, COMMON CAUSE, IMPROVE COBRA IIIC/MIT AND WATER HAMMER
AU - BROWNING, E.W.
CS - SENIOR STAFF ENGINEER CONSUMERS POWER CO. (MI) (517)788-2201
DA - START - 781001; COMPLETION - 800131; DATE OF UPDATE - 840929
NU - CPC9031
AB - OBJECTIVES OF THIS PROJECT WERE - (1) TO IMPROVE THE FUEL PIN AND FUEL CLADDING MODELS AND IMPROVE THE CODES RANGE IN BWR APPLICATIONS; (2) TO EXTEND THERMIT TO SUBCHANNEL GEOMETRICS,

APPLICATIONS; (2) TO EXTEND THERMIT TO SUBCHANNEL GEOMETRICS, ALLOWING APPLICATION AS A BENCHMARK CODE TO SEVERAL ECCS AND ATWS EVENTS; (3) TO DEVELOP TECHNIQUES WHICH WILL ALLOW UTILITIES TO MAKE QUALITATIVE EVALUATIONS OF SYSTEM UNAVAILABILITY RESULTING FROM A COMMON CAUSE (OR COMMON MODE FAILURE); AND (4) TO DEVELOP SOME FUNDAMENTAL DATA REQUIRED TO APPROPRIATELY MODEL WATER HAMMER, AND TO STUDY THE EVOLUTION OF A PRESSURE "SIGNATURE" AS A BUBBLE COLLAPSE SOURCE SIGNAL IS TRANSMITTED THROUGH PIPING.

14. TI - THERMAL HYDRAULIC ASPECTS OF REACTOR/PLANT ENGINEERING AND SAFETY ANALYSIS WATER HAMMER IN NUCLEAR SYSTEMS
AU - PITEK, MARTIN T.
CS - NUCLEAR ENERGY CONVERSION RES. SCIENTIST NORTHEAST UTILITIES (203)665-5210
AU - START - 780901; COMPLETION - 820630; DATE OF UPDATE - 880413
NU - NU7899-4P
AB - THE OBJECTIVE IS TO CONDUCT BOTH EXPERIMENTAL AND ANALYTICAL INVESTIGATION OF - (1) STEAM BUBBLE COLLAPSE AS A MECHANISM TO BETTER UNDERSTAND AND REPRESENT THE ASSUMED MAJOR FORCING FUNCTION FOR WATER HAMMER; AND (2) METHODS FOR CALCULATING THE PRESSURE SIGNATURE THAT RESULTS FROM STEAM BUBBLE COLLAPSE, ACCOUNTING FOR THE PIPE PROPERTIES, SYSTEM GEOMETRIES, AND OTHER SYSTEM-SPECIFIC FEATURES THAT MAY AFFECT THIS SIGNATURE.

15. TI - PIPING SYSTEM DAMPING DATA AT HIGHER FREQUENCIES
AU - WARE, A.G.
PU - 1987; 11P; PAPER COPY ONLY, COPY DOES NOT PERMIT MICROFICHE PRODUCTION NATIONAL CONGRESS ON PRESSURE VESSELS AND PIPING, SAN DIEGO, CA, USA, 28 JUN 1987; PC A02
AB - RESEARCH HAS BEEN PERFORMED AT THE IDAHO NATIONAL ENGINEERING LABORATORY (INEL) FOR THE UNITED STATES NUCLEAR REGULATORY COMMISSION (USNRC) TO DETERMINE BEST-ESTIMATE DAMPING VALUES FOR DYNAMIC ANALYSES OF NUCLEAR PIPING SYSTEMS EXCITED IN THE 20 TO 100 HZ FREQUENCY RANGE. VIBRATIONS IN THIS FREQUENCY RANGE ARE TYPICAL OF FLUID-INDUCED TRANSIENTS, FOR WHICH NO FORMAL PIPE DAMPING GUIDELINES EXIST. THE AVAILABLE DATA FOUND IN THE OPEN LITERATURE AND THE USNRC/INEL NUCLEAR PIPING DAMPING DATA BANK WERE REVIEWED, AND A SERIES OF TESTS ON A STRAIGHT 3-IN. (76-MM) PIPING SYSTEM AND A 5-IN. (127-MM) SYSTEM WITH SEVERAL BENDS AND ELBOWS WERE CONDUCTED AS PART OF THIS RESEARCH PROGRAM. THESE TWO SYSTEMS WERE SUPPORTED WITH TYPICAL NUCLEAR PIPING SUPPORTS THAT COULD BE CHANGED FROM TEST TO TEST DURING THE SERIES. THE RESULTING DAMPING VALUES WERE GREATER THAN OR EQUAL TO THOSE OF THE PRESSURE VESSEL RESEARCH COMMITTEE (PVRC) PROPOSAL FOR UNINSULATED PIPING, EXTENDING THE PVRC DAMPING CURVE REPRESENTATION OF THE TEST DATA. THIS POSITION HAS BEEN ENDORSED BY THE PVRC TECHNICAL COMMITTEE ON PIPING SYSTEMS. 14 REFS. (ERA CITATION 12 -032831)

16. TI - PRELIMINARY TESTS OF DIRECT WATER CONTACT CONDENSATION OF STEAM
AU - NELSON, D.R.
CS - GENERAL ELECTRIC COMPANY, SAN JOSE, CA, ATOMIC POWER EQUIPMENT DEPARTMENT
PU - 14 MAY 58; 9P; PORTIONS OF THIS DOCUMENT ARE ILLEGIBLE IN MICROFICHE PRODUCTS; PC A02/MF A01

AB - STEAM WAS DISCHARGED INTO A TANK OF WATER TO PERMIT OBSERVATION OF THE PHENOMENA OF DIRECT WATER CONTACT STEAM CONDENSATION AND TO ATTEMPT TO ESTABLISH AN ORDER OF MAGNITUDE FOR THE EFFICIENCY OF STEAM CONDENSATION AND THE SHOCK WAVE OR WATER HAMMER EFFECTS OF THE CONDENSATION COLLAPSE OF STEAM BUBBLES.

17. TI - STATE-OF-THE-ART LITERATURE REVIEW OF WATER HAMMER.
AU - WATKINS, J.C.; BERRY, R.A.
CS - IDAHO NATIONAL ENGINEERING LAB, IDAHO FALLS, USA
PU - APR 79; 116P; PC A06/MF A01

18. TI - LOFT LOCA - WHAM6 MODEL AND CODE APPLICATION
AU - BERTA, V.T.
CS - IDAKO NATIONAL ENGINEERING LAB., IDAHO FALLS.; DEPARTMENT OF ENERGY.
PU - 27 JUL 78; 40P; PORTIONS OF DOCUMENT ARE ILLEGIBLE; PC A03/MF A01
NU - CONT. EY-76-C-07-1570

19. TI - BROWNS FERRY NUCLEAR POWER STATION, UNIT 1. CORRECTIVE ACTION TAKEN AFTER INSPECTION OF DECEMBER 14 AND 20-21, 1972.
CS - TENNESSEE VALLEY AUTHORITY, CHATTANOOGA.
PU - 2 MAY 73; 29P

20. TI - OYSTER CREEK NUCLEAR POWER PLANT, UNIT 1. CORE SPRAY SYSTEM WATER HAMMER PHENOMENON.
CS - JERSEY CENTRAL POWER AND LIGHT CO., MORRISTOWN, N.J.
PU - 3 OCT 72; 11P

21. TI - OYSTER CREEK NUCLEAR POWER PLANT, UNIT NO. 1. CORE SPRAY SYSTEM WATER HAMMER.
CS - JERSEY CENTRAL POWER AND LIGHT CO., MORRISTOWN, N.J.
PU - 15 DEC 71; 40P

22. TI - DRESDEN NUCLEAR POWER STATION, UNIT 2. SUPPLEMENTARY INFORMATION TO SPECIAL REPORT NO. 13- CORE SPRAY WATER HAMMER INCIDENT.
CS - COMMONWEALTH EDISON CO., CHICAGO, ILL.
PU - 24 JUN 71; 5P

23. TI - OYSTER CREEK NUCLEAR POWER PLANT, UNIT NO. 1. CORE SPRAY SYSTEM WATER HAMMER.
CS - JERSEY CENTRAL POWER AND LIGHT CO., MORRISTOWN, N.J.
PU - 25 JUN 71; 3P

24. TI - ANALOG ANALYSIS OF FLOW REVERSAL AND WATER HAMMER PRESSURE IN A TYPICAL CLOSED AARR HYDRAULIC RABBIT-TUBE FACILITY.
AU - ROHDE, RAYMOND R.; WINIECKI, ALAN L.
CS - ARGONNE NATIONAL LAB., ILL.; 033 550
PU - AUG 67; 23P; PC A02/MF A01
NU - CONT. W-31-109-ENG-38

25. TI - ORIGIN AND MAGNITUDE OF PRESSURES IN FUEL-COOLANT INTERACTIONS.
AU - HEER, W.; JAKEMAN, D.; SMITH, B.L.
CS - FEDERAL INST FOR REACTOR RESEARCH, WUERENLINGEN, WEST GERMANY
PU - PUBL FOR BRITISH NUCLEAR ENERGY SOC BY THOMAS TELFORD LTD, LONDON, ENGLAND V 2, P 491-496, 1986; 5 REFS.

NU - 11555; ISBN 0-7277-0359-5

AB - A NUMBER OF SMALL SCALE EXPERIMENTS TO SIMULATE FUEL COOLANT INTERACTION (FCI) EFFECTS HAVE BEEN CARRIED OUT USING FREON AND WATER. CONTRARY TO THE PREDICTIONS OF MOST CURRENT FCI MODELS, ONLY MODEST PRESSURE TRANSIENTS ARE OBSERVED WITHIN THE INTERACTION REGION ITSELF BY LARGE PRESSURE SPIKES, NEAR TO OR ABOVE CRITICAL FREON PRESSURE, ARE SEEN AT THE BOUNDARIES OF THE REGION. SIMILAR PRESSURE AMPLIFICATION EFFECTS HAVE BEEN NOTICED IN PARALLEL EXPERIMENTS INVOLVING TWO PHASE MIXTURES. IT IS SUGGESTED THAT IN BOTH CASES A WATER HAMMER TYPE EFFECT IS THE CAUSE OF THE PRESSURE SPIKES. THESE OBSERVATIONS COULD FORM THE BASIS OF NEW THINKING IN FCI MODELLING. (AUTHOR ABSTRACT)

26. TI - HDR-INVESTIGATIONS OF CHECK VALVE CLOSURE AND RESULTANT WATER HAMMER EFFECTS.

AU - SCHOLL, K. -H.

PU - TRANSACTIONS OF THE INTERNATIONAL CONFERENCE ON STRUCTURAL MECHANICS IN REACTOR TECHNOLOGY 7TH PUBL FOR COMMISSION OF THE EUROPEAN COMMUNITIES (EUR-8596) BY NORTH-HOLLAND, AMSTERDAM, NETH AND NEW YORK, NY, USA B7. 6, P 401-408, 1983; 4 REFS

AB - THE INVESTIGATIONS IN THIS PAPER ARE BASED ON THE LOSS OF COOLANT ACCIDENT (LOCA). THEY CONCENTRATE ON THE FIRST BLOWDOWN PHASE AFTER PIPE BREAK OF A FEEDWATER LINE. THE EFFECT OF SUCH A BREAK IS MODERATED BY QUICK CLOSING CHECK VALVES, BY WHICH THE LOSS OF COOLANT WATER IS REDUCED AND OPTIMAL POST ACCIDENT CONDITIONS ARE OBTAINED. THE FEEDWATER SYSTEM LOADING BY HIGH PRESSURE EFFECTS HAS BEEN ANALYZED. THE RESULTS LED TO AN IMPROVEMENT OF THE FEEDWATER SYSTEM SAFETY BY VERIFYING DAMPING MEASURES OF QUICK CLOSING CHECK VALVES. (EDITED AUTHOR ABSTRACT)

27. TI - BLOWDOWN PHENOMENA MODELLING IN PRESSURIZED WATER REACTORS BY SHOCK WAVE ANALYSIS.

AU - ENSHARAH, AHMED E.; EL-SAIEDI, A.F.; NAGY, M.E.

PU - MODELLING AND SIMULATION, PROCEEDINGS OF THE ANNUAL PITTSBURGH CONFERENCE 15TH. PUBL BY ISA, RESEARCH TRIANGLE PARK, NC, USA P 1817-1826, 1984; 16 REFS.

AB - THE PROPER TREATMENT OF SEVERAL REACTOR SAFETY PROBLEMS REQUIRES THE KNOWLEDGE OF HOW PRESSURE WAVES PROPAGATE WITHIN THE REACTOR COMPONENTS CONTAINING TWO-PHASE MIXTURE MEDIA, EXACTLY OCCURRED IN THE BLOWDOWN PHASE OF GUILLOTINE LOCA IN A LARGE PRESSURIZED WATER REACTORS(LPWR). A HYDRODYNAMIC CODE IS DEVELOPED DESCRIBING THE SYSTEM BEHAVIOUR IN SUCH CASE. THE GOVERNING EQUATIONS AS WELL AS THE METHOD OF SOLUTION WITH THE NUMERICAL TECHNIQUE USED ARE ALL PRESENTED. DETAILED SYSTEM FORMULA OF THE CRITICAL FLOW DISCHARGE FROM THE RUPTURE AND THE EFFECT OF FRICTIONAL LOSS ON THE DECOMPRESSION ARE ALSO PRESENTED. THE MODEL IS TESTED AGAINST BOTH A TYPICAL 3000 MWT PWR AND THE LOFT-L2-2 TEST. (AUTHOR ABSTRACT)

28. TI - INVESTIGATIONS ON REDUCING DYNAMIC LOADS IN BMR PRESSURE RELEASE PROCESSES/UNTERSUCHUNGEN ZUR VERMINDERUNG DER DYNAMISCHEN LASTEN BEI SWR DRUCKABRAU BORGENGEN.

AU - SCHULTHEISS, G.F. GES FUER KERNENERGIEVRERWERT IN SCHIFFBAU; SAKKAL, F.

PU - TAGUNGSBERICHT - JAHRESTAGUNG KERNTECHNIK 1982. PUBL BY DTSCH ATOMFORUM, BONN, GER P 211-214, 1982

29. TI - EFFICIENT PROCEDURE FOR EVALUATING DYNAMIC RESPONSES OF PIPING SYSTEM TO WATER/STEAM HAMMER EVENTS
AU - YEH, G.C.K.; HOH, F.K.C.
PU - TRANSACTIONS OF THE INTERNATIONAL CONFERENCE ON STRUCTURAL MECHANICS IN REACTOR TECHNOLOGY 6TH. PUBL BY NORTH-HOLLAND PUBL CO, AMSTERDAM, NETH, FOR COMM OF THE EUR COMMUNITIES (EUR 7146), BRUSSELS, BELG. DISTRIB IN USA AND CAN BY ELSEVIER NORTH-HOLLAND, NEW YORK, NY, USA F 5. 3, 1P, 1981

30. TI - PEC REACTOR TEST LOOP RESPONSE TO ENERGY EXCURSIONS
AU - CENERINI, R.; PALAMIDESSI, A.; SCOTT, E.
PU - TRANSACTIONS OF THE INTERNATIONAL CONFERENCE ON STRUCTURAL MECHANICS IN REACTOR TECHNOLOGY 6TH. PUBL BY NORTH-HOLLAND PUBL CO. AMSTERDAM, NETH, FOR COMM OF THE EUR COMMUNITIES (EUR 7146), BRUSSELS, BELG. DISTRIB IN USA AND CAN BY ELSEVIER NORTH-HOLLAND, NEW YORK, NY, USA E 3. 9, 7P, 1981

31. TI - EXAMINATION OF THE DESTRUCTIVE FORCES IN THE CHERNOBYL ACCIDENT BASED ON NSRR EXPERIMENTS
AU - SOBAJUMA, M.; FUJISHIRO, T.
PU - NUCL. ENG. DES. (NETHERLANDS), FEB 1988, 106(2), P 179-90.
AB - THE POSSIBLE CAUSES OF THE DESTRUCTION OF THE CHERNOBYL REACTOR CORE WERE EXAMINED BY MAKING USE OF THE NUCLEAR SAFETY RESEARCH REACTOR (NSRR) EXPERIMENTAL RESULTS CONCERNING THE DESTRUCTIVE FORCES GENERATED BY A FUEL FAILURE. A COMPLEMENTARY EXPERIMENT WITH CHERNOBYL REACTOR CONDITIONS WAS PERFORMED IN ORDER TO OBSERVE THE FUEL FAILURE BEHAVIOUR AND THE RESULTANT VESSEL PRESSURE RISE, ETC. ALSO, THE GENERATION OF HYDROGEN FROM THE FUEL ROD CLADDING AND THE CONSEQUENT SYSTEM PRESSURE RISE WERE ESTIMATED BASED ON THE EXPERIMENTS. THESE EXAMINATIONS LED TO THE CONCLUSION THAT THE MOST PROBABLE CAUSE OF THE CORE PRESSURE TUBE RUPTURE IN THE ACCIDENT WAS A STATIC PRESSURE RISE DUE TO RAPID ENERGY RELEASE FROM FRAGMENTED FUEL. OTHER PHENOMENA SUCH AS THE HYDROGEN GENERATION AND MOLTEN FUEL CONTACT TO THE TUBE WALL MIGHT HAVE CONTRIBUTED TO THE TUBE RUPTURE. THE WATER HAMMER FORCE IS ALSO ESTIMATED TO HAVE BEEN LARGE ENOUGH TO BREAK TUBES EVEN USING CONSERVATIVE ASSUMPTIONS.

32. TI - PIPE RUPTURE AND STEAM/WATER HAMMER DESIGN LOADS FOR DYNAMIC ANALYSIS OF PIPING SYSTEMS
AU - STRONG, B.R., JR.; BASCHIERE, R.J.
PU - NUCL. ENG. AND DES. (NETHERLANDS), FEB 1978, 45(2), P. 419-28.

33. TI - THE MODELLING OF CHUGGING LOADS IN PRESSURE SUPPRESSION SYSTEMS.
AU - SCHWEIGER, W. (GESELLSCHAFT FUER TECHNISCH-WISSENSCHAFTLICHE DATENVERARBEITUNG M.B.H., PUCHHEIM (GERMANY, F.R.)); SCHWINGES, B. (GESELLSCHAFT FUER REAKTORSICHERHEIT M.B.H. (GRS), KOELN (GERMANY, F.R.)).; 2795680
PU - P. 105-112. TRANSACTIONS OF THE 7. INTERNATIONAL CONFERENCE ON STRUCTURAL MECHANICS IN REACTOR TECHNOLOGY. VOL. J. LOADING CONDITIONS AND STRUCTURAL ANALYSIS OF REACTOR CONTAINMENT. AMSTERDAM (NETHERLANDS). NORTH-HOLLAND. 1983. 543 P.

34. TI - EVALUATION OF DYNAMIC LOADS DUE TO BUBBLE OSCILLATION CAUSED BY S/RV ACTUATION.
AU - ARINOBU, M.; SHIOYAMA, T. (TOSHIBA CORP., KAWASAKI, KANAGAWA (JAPAN). RESEARCH AND DEVELOPMENT CENTER); SHIHO, E. (TOSHIBA CORP., YOKOHAMA (JAPAN). NUCLEAR ENERGY GROUP). 9309120;
PU - P. 67-74. TRANSACTIONS OF THE 7. INTERNATIONAL CONFERENCE ON STRUCTURAL MECHANICS IN REACTOR TECHNOLOGY. VOL. J. LOADING CONDITIONS AND STRUCTURAL ANALYSIS OF REACTOR CONTAINMENT. AMSTERDAM (NETHERLANDS). NORTH-HOLLAND. 1983. 543 P.

35. TI - EXPERIMENTAL RESULTS ABOUT DYNAMIC LOAD MITIGATION FOR BWR-PRESSURE SUPPRESSION CONTAINMENTS UNDER LOCA-CONDITIONS.
AU - AUST, E.; SCHULTHEISS, G.F.; SEELIGER, D. (GKSS-FORSCHUNGSZENTRUM GEESTHACHT G.M.B.H., GEESTHACHT-TESPERHUDE (GERMANY, F.R.). INST. FUER ANLAGENTECHNIK); MCCAULEY, E.W. (CALIFORNIA UNIV., LIVERMORE (USA). LAWRENCE LIVERMORE NATIONAL LAB.). 2818650; 9513035
NU - EUR--8596 DE/EN/FR.; ISBN 0444 86697 3.
PU - P. 43-50. TRANSACTIONS OF THE 7. INTERNATIONAL CONFERENCE ON STRUCTURAL MECHANICS IN REACTOR TECHNOLOGY. VOL. J. LOADING CONDITIONS AND STRUCTURAL ANALYSIS OF REACTOR CONTAINMENT. AMSTERDAM (NETHERLANDS). NORTH-HOLLAND. 1983. 543 P.

36. TI - SOURCE AND LOADING CONDITIONS IN PRESSURE SUPPRESSION SYSTEMS - RESULTS OF THE MULTIVALENT LARGE SCALE PRESSURE SUPPRESSION EXPERIMENTS.
AU - AUST, E.; BOETTCHER, G.; KOLB, M.; VOLLBRANDT, J. (GKSS-FORSCHUNGSZENTRUM GEESTHACHT G.M.B.H., GEESTHACHT-TESPERHUDE (GERMANY, F.R.). INST. FUER ANLAGENTECHNIK); MCCAULEY, E.W.; HOLMAN, G.S. (CALIFORNIA UNIV., LIVERMORE (USA). LAWRENCE LIVERMORE NATIONAL LAB.). 2818650; 9511304
PU - VP. STRUCTURAL MECHANICS IN REACTOR TECHNOLOGY. VOL. J(A). LOADING CONDITIONS AND STRUCTURAL ANALYSIS OF REACTOR CONTAINMENT. AMSTERDAM, NETHERLANDS. NORTH-HOLLAND PUBLISHING CO. 1981. 325 P.

37. TI - MULTIVENT FULL-SCALE TEST ON MARK II PRESSURE SUPPRESSION SYSTEM.
AU - NAMATAME, K.; KUKITA, Y.; TAKESHITA, I.; SHIBA, M. (JAPAN ATOMIC ENERGY RESEARCH INST., TOKAI, IBARAKI. REACTOR SAFETY LAB.).
PU - VP. STRUCTURAL MECHANICS IN REACTOR TECHNOLOGY. VOL. J(A). LOADING CONDITIONS AND STRUCTURAL ANALYSIS OF REACTOR CONTAINMENT. AMSTERDAM, NETHERLANDS. NORTH-HOLLAND PUBLISHING CO. 1981. 325 P.

38. TI - RESPONSE OF A BWR MARK II CONTAINMENT STRUCTURE TO SRV LOADS.
AU - BEDROSIAN, B.; BRENNAN, J.; KASK, P.K.; ETTOUNEY, M.M. (BURNS AND ROE, INC., NEW YORK (USA)). 1039000
PU - VP. STRUCTURAL MECHANICS IN REACTOR TECHNOLOGY. VOL. J(A). LOADING CONDITIONS AND STRUCTURAL ANALYSIS OF REACTOR CONTAINMENT. AMSTERDAM, NETHERLANDS. NORTH-HOLLAND PUBLISHING CO. 1981. 325 P.

39. TI - ADMISSIBLE BLOWDOWN LOADING FOR SHERICAL CONTAINMENTS WITH PRESSURE SUPPRESSION SYSTEM.
AU - KRIEG, R.; GOELLER, B.; HAILFINGER, G. (KERNFORSCHUNGSZENTRUM KARLSRUHE G.M.B.H. (GERMANY, F.R.). INST. FUER REAKTORENTWICKLUNG). 3590000

PU - VP. STRUCTURAL MECHANICS IN REACTOR TECHNOLOGY. VOL. J(A). LOADING CONDITIONS AND STRUCTURAL ANALYSIS OF REACTOR CONTAINMENT. AMSTERDAM, NETHERLANDS. NORTH-HOLLAND PUBLISHING CO. 1981. 325 P.

40. TI - BEHAVIOR OF WATER JET FROM THE DOWNCOMER VENT DURING POST WATER CLEARING PHASE OF A LOCA IN A BWR MARK II CONTAINMENT.
AU - BEDROSIAN, B.; SHAH, A.A.; WALTERS, J. (BURNS AND ROE, INC., NEW YORK (USA)); CHU, C.K. (COLUMBIA UNIV., NEW YORK (USA). DEPT. OF APPLIED PHYSICS AND NUCLEAR ENGINEERING). 1039000; 9509272
PU - VP. STRUCTURAL MECHANICS IN REACTOR TECHNOLOGY. VOL. J(A). LOADING CONDITIONS AND STRUCTURAL ANALYSIS OF REACTOR CONTAINMENT. AMSTERDAM, NETHERLANDS. NORTH-HOLLAND PUBLISHING CO. 1981. 325 P.

41. TI - RESPONSE OF A BWR MARK II CONTAINMENT STRUCTURE TO CHUGGING LOADS.
AU - BEDROSIAN, B.; ETTOUNEY, M. (BURNS AND ROE, INC., WOODBURY, NY (USA)). JAEGER, T.A.; BOLEY, B.A. (EDS.).
PU - P. J2/7 (1-8). STRUCTURAL MECHANICS IN REACTOR TECHNOLOGY. TRANSACTIONS. VOL. J. LOADING CONDITIONS AND STRUCTURAL ANALYSIS OF REACTOR CONTAINMENT. AMSTERDAM, NETHERLANDS. NORTH-HOLLAND PUBLISHING CO. 1979.

42. TI - ANALYSIS TO JUSTIFY INCREASED ALLOWABLE STRESSES FOR THE MARK I VENT HEADER WHEN SUBJECTED TO POOL SWELL IMPACT LOADING. (BWR.)
AU - KENNEDY, R.P.; CAMPBELL, R.D.; NARVER, R.B.
OR - ENGINEERING DECISION ANALYSIS CO., PALO ALTO, CA, USA
PU - MAY 1978. 44 P.

43. TI - INVESTIGATION OF WALL LOADS GENERATED BY VAPOR CONDENSATION IN THE BWR PRESSURE SUPPRESSION SYSTEM. (IN GERMAN). UNTERSUCHUNG DER BEI DER DAMPFKONDENSATION IM DRUCKABBAUSYSTEM VON SIEDEWASSERREAKTOREN ENTSTEHENDEN WANDBELASTUNG.
AU - CLASS, G.
CS - KERNFORSCHUNGSZENTRUM, KARLSRUHE, GERMANY
PU - MAR 1978. 43 P.

44. TI - DYNAMIC LOADING OF CONTAINMENT DURING BLOW-DOWN. REVIEW OF EXPERIMENTAL DATA FROM MARVIKEN UND BRUNSBUETTEL.
AU - KADLEC, J.; MUELLER, R.A. (KERNFORSCHUNGSZENTRUM KARLSRUHE (F.R. GERMANY). INST. FUER REAKTORENTWICKLUNG). 3590000 JAEGER, T.A. (COMP.).
PU - EXTREME LOAD CONDITIONS AND STRUCTURAL ANALYSIS OF REACTOR CONTAINMENTS. 1975. VP.

45. TI - FUNCTIONALITY AND LEAK INTEGRITY OF CONTAINMENT PENETRATION SYSTEMS SUBJECTED TO DESIGN BASE DYNAMIC LOADS.
AU - HILL, R.C.; CLOSE, J.A.
OR - IDAHO NATIONAL ENGINEERING LAB., IDAHO FALLS, USA
PU - 12 SEP 1986. 7 P.

46. TI - TRANSIENT BOILING HEAT TRANSFER IN A NARROW CHANNEL. FLUCTUATION PHENOMENA IN THE CHANNEL DUE TO BUBBLE GROWTH AND COLLAPSE.
AU - OKUYAMA, KUNITO (JAPAN ATOMIC ENERGY RESEARCH INST., TOKAI, IBARAKI. TOKAI RESEARCH ESTABLISHMENT); AOKI, SHIGEBUMI; KOZAWA, YOSHIYUKI; INOUE, AKIRA.

PU - BULL. JSME (JPN. SOC. MECH. ENG.). (JUL 1986). V. 29(253) P. 2122-2130.

47. TI - TRANSIENT BOILING HEAT TRANSFER IN A NARROW CHANNEL, (3). FLUCTUATION PHENOMENA IN THE CHANNEL DUE TO BUBBLE GROWTH AND COLLAPSE. (IN JAPANESE).
AU - OKUYAMA, KUNITO; AOKI, SHIGEBUMI; KOZAWA, YOSHIYUKI; INOUE, AKIRA (TOKYO INST. OF TECH. (JAPAN)). 6259000
PU - NIPPON KIKAI GAKKAI RONBUNSHU, B HEN. (NOV 1985). V. 51(471) P. 3539-3547.

48. TI - NUMERICAL ANALYSIS ON PRESSURE PROPAGATION IN PRESSURE SUPPRESSION SYSTEM DUE TO STEAM BUBBLE COLLAPSE.
AU - UTAMURA, MOTOAKI (HITACHI LTD., IBARAKI (JAPAN). ENERGY RESEARCH LAB.); MORIYA, KUMIAKI; UOZUMI, HIROTO. 9309020
PU - J. NUCL. SCI. TECHNOL. (TOKYO). (APR 1984). V. 21(4) P. 279-287.

49. TI - STEAM BUBBLE COLLAPSE, WATER HAMMER AND PIPING NETWORK RESPONSE. VOLUME II. PIPING NETWORK RESPONSE TO STEAM GENERATED WATER HAMMER. FINAL REPORT.
AU - GRUEL, R.; HURWITZ, W.; HUBER, P.; GRIFFITH, P.
OR - MASSACHUSETTS INST. OF TECH., CAMBRIDGE (USA). ENERGY LAB. 9500636
NU - PB--81-140444.
PU - JUN 1980. 83 P.

50. TI - STEAM BUBBLE COLLAPSE, WATER HAMMER AND PIPING NETWORK RESPONSE. VOLUME I. STEAM BUBBLE COLLAPSE AND WATER HAMMER IN PIPING SYSTEMS - EXPERIMENTS AND ANALYSIS. FINAL REPORT.
AU - GRUEL, R.; HURWITZ, W.; HUBER, P.; GRIFFITH, P.
OR - MASSACHUSETTS INST. OF TECH., CAMBRIDGE (USA). ENERGY LAB. 9500636
NU - PB--81-140436.
PU - JUN 1980. 50 P.

51. TI - AN ENGINEERING CONCEPT FOR THE STEAM BUBBLE COLLAPSE ANALYSIS IN THE LICENSING PROCEDURE.
AU - GIENCKE, E. (TECHNISCHE UNIV. BERLIN (GERMANY, F.R.)). 6128100 SCHULTHEISS, G.F. (ED.).
OR - GKSS-FORSCHUNGSZENTRUM GEESTHACHT G.M.B.H., GEESTHACHT-TESPERHUDE (GERMANY, F.R.). 2818600
NU - GKSS--81/E/28.
PU - P. V 13-40. PROCEEDINGS OF THE INTERNATIONAL SPECIALIST MEETING ON BWR-PRESSURE SUPPRESSION CONTAINMENT TECHNOLOGY. VOL. 2. PAPERS AND INFORMATION MATERIAL. 1981. 291 P.

52. TI - PRESSURE DISTRIBUTION DUE TO STEAM BUBBLE COLLAPSE IN A BWR PRESSURE SUPPRESSION POOL.
AU - GIENCKE, E. (TECHNISCHE UNIV. BERLIN (GERMANY, F.R.). INST. FUER LUFT-UND RAUMFAHRT).
PU - NUCL. ENG. DES. (JUN 1981). V. 65(2) P. 175-196.

53. TI - THEORETICAL EVALUATION OF A STEAM BUBBLE COLLAPSE IN THE FEEDWATER SYSTEM OF A NUCLEAR PLANT.
AU - WARREN, A.H. (AM ELECTR POWER SERV CORP, NEW YORK, NY).
NU - ISSN 0065-8812.

PU - AICHE SYMP. SER. (1980). V. 76 P. 1-13.

54. TI - PRESSURE DISTRIBUTION DUE TO STEAM BUBBLE COLLAPSE IN A BWR SUPPRESSION CHAMBER.
AU - GIENCKE, E. (TECHNISCHE UNIV. BERLIN (GERMANY, F.R.). LEHRSTUHL UND INST. FUER KONSTRUKTIONSLEHRE). JAEGER, T.A.; BOLEY, B.A. (EDS.).
PU - P. B7/1 (1-8). STRUCTURAL MECHANICS IN REACTOR TECHNOLOGY. TRANSACTIONS.VOL. B. THERMAL AND FLUID/STRUCTURE DYNAMICS ANALYSIS. AMSTERDAM, NETHERLANDS. NORTH-HOLLAND PUBLISHING CO. 1979.

55. TI - LOCA STEAM CONDENSATION LOADS IN BWR MARK II PRESSURE SUPPRESSION CONTAINMENT SYSTEM
AU - KUKITA, Y.; NAMATAME, K.; TAKESHITA, I.; SHIBA, M.
PU - NUCL. ENG. AND DES. (NETHERLANDS)
1987 ; 102(2); P. 225-8 ; 6 REFS

56. TI - PRESSURE DISTRIBUTION DUE TO A STEAM BUBBLE COLLAPSE IN A BWR PRESSURE SUPPRESSION POOL
AU - GIENCKE, E.
PU - NUCL. ENG. AND DES. (NETHERLANDS)
JUNE 1981 ; 65(2); P. 175-96 ; 8 REFS

57. TI - TURBULENT STEAM CONDENSATION IN A HORIZONTAL CHANNEL
AU - SEGEV, A.; COLLIER, R.P.; HOYT, J.W.
PU - CAVITATION AND POLYPHASE FLOW FORUM-1980. PRESENTED AT THE JOINT MEETING OF THE FLUIDS ENGINEERING DIVISION AND THE GAS TURBINE DIVISION, ASME
Publ - NEW YORK, USA ; ASME
1980 ; P. 45-6 ; 46 P.; 0 REFS

58. TI - DIRECT CONTACT CONDENSATION OF STEAM BUBBLES IN WATER AT HIGH PRESSURE
AU - BRUCKER, G.; SPARROW, E.M.
PU - INT. J. HEAT AND MASS TRANSFER (GB)
RE - A707453

59. TI - PRESSURE FIELD PRODUCED BY THE COLLAPSE OF A CAVITATION VOID
AU - LEVKOVSKII, YU. L.
PU - AKUST. ZN. (USSR)
APRIL 1969 ; 15(2); 239-43
Translated in - SOVIET PHYSICS ACOUSTICS (USA)
OCT. 1969 ; 15(2); 205-8
APRIL 1977 ; 20(4); 371-81

60. TI - PRESSURE VESSEL INTEGRITY AND WELD INSPECTION PROCEDURE.
AU - SOLOMON, K. A.; OKRENT, D.; KASTENBERG, W. E.
CS - CALIFORNIA UNIV., LOS ANGELES. SCHOOL OF ENGINEERING AND APPLIED SCIENCE.; NATIONAL SCIENCE FOUNDATION, WASHINGTON, D.C. RESEARCH APPLIED TO NATIONAL NEEDS.
PU - FEB 75; 136P; REPORT ON A GENERAL EVALUATION APPROACH TO RISK-BENEFIT FOR LARGE TECHNOLOGICAL SYSTEMS AND ITS APPLICATION TO NUCLEAR POWER; PC A07/MF A01
NU - REPT. UCLA-ENG-7496; NSF/RA/X-75/026
GRANT NSF-GI-39416

AB - THIS REPORT PRESENTS THE RESULTS OF AN INTERNATIONAL SURVEY ON THE SUBJECT OF VIBRATION IN NUCLEAR PRIMARY COOLANT PUMPS DUE TO TWO-PHASE FLOW, ACCIDENT CONDITIONS. THE LITERATURE SEARCH ALSO REVEALED FEW CANADIAN REFERENCES OTHER THAN THOSE OF ONTARIO HYDRO. ONTARIO HYDRO'S WORK HAS BEEN EXTENSIVE. CONFIDENCE IN THE MECHANICAL INTEGRITY OF THE PUMPSETS IS GOOD, GIVEN THE EXTENT OF THE TESTING. HOWEVER, CONCLUSIONS WITH RESPECT TO PIPING INTEGRITY AND THERMAL-HYDRAULIC PERFORMANCE ARE DIFFICULT TO DETERMINE DUE TO THE INEXACT GEOMETRY OF THE PIPING AND THE DIFFICULTIES IN ESTIMATING FLUID CONDITIONS AT THE PUMP. THE TESTS HELP TO UNDERSTAND THE PHENOMENA AND PROVIDE BACKGROUND INFORMATION FOR ANALYSIS, BUT SHOULD BE APPLIED WITH CAUTION TO PLANT ANALYSES. MUCH OF THE DISCUSSION IN THE REPORT RELATES TO PUMP HEAD INSTABILITY. THIS IS PERCEIVED TO BE THE MOST IMPORTANT FLOW REGIME CAUSING VIBRATION, AS ATTESTED BY THE EMPHASIS OF THE REVIEWED LITERATURE. A METHOD FOR QUANTITATIVE ASSESSMENT OF THE FORCING FUNCTIONS ACTING ON THE PUMP-PIPING SYSTEM DUE TO VOID GENERATION AND COLLAPSE IS RECOMMENDED. A RELATIVELY FUNDAMENTAL ANALYTICAL APPROACH IS PROPOSED, SUPPLEMENTED BY REDUCED SCALE TESTING IN THE LATTER STAGES. 151 REFS. (ATOMINDEX CITATION 19:046544)

61. TI - INDEX OF NATIONAL ENGINEERING LABORATORY (NEL) PUBLICATIONS, 1978-1980.

CS - NATIONAL ENGINEERING LAB., EAST KILBRIDE (SCOTLAND).; NI131490

PU - AUG 82; 36P; PC A03/MF A01

NU - REPT. WEL-682

AB - REFERENCES WITH SUMMARIES ARE GIVEN FOR ALL REPORTS AND PAPERS PUBLISHED DURING THE YEARS 1978 TO 1980 BY THE STAFF OF THE NATIONAL ENGINEERING LABORATORY (NEL); THESE ARE ARRANGED BY SUBJECT. ALSO INCLUDED ARE LISTS OF PAPERS READ AT NEL SYMPOSIA AND CONFERENCES AND A NUMERICAL LIST OF NEL REPORTS WITH SHORTENED SUMMARIES.

62. TI - EFFECTS OF TORUS WALL FLEXIBILITY ON FORCES IN THE MARK I BWR PRESSURE SUPPRESSION SYSTEM UNDER SRV T-QUENCHER LOADING.

AU - HOLMAN, G. S.; LU, S. C.

CS - CALIFORNIA UNIV., LIVERMORE. LAWRENCE LIVERMORE LAB.; 005415009 9500007

PU - 15 JAN 80; 25P; ASME CENTURY 2 EMERGING TECHNOLOGY CONFERENCE, SAN FRANCISCO, CA, USA, 10 AUG 1980; PC A02/MF A01

NU - REPT. CONF-800804-12
CONT. W-7405-ENG-48

AB - THIS REPORT DESCRIBES A SERIES OF EXTENDED ANALYSES REQUESTED BY THE US NUCLEAR REGULATORY COMMISSION TO PROVIDE QUALIFIED UNDERSTANDING OF POSSIBLE FLUID/STRUCTURE INTERACTION (FSI) EFFECTS FOR SRV TEEQUENCHER TEST RESULTS. THREE INPUT PULSES WITH TOTAL IMPULSES VARYING BY UP TO A FACTOR OF FIVE ARE APPLIED TO TWO-DIMENSIONAL FINITE-ELEMENT MODELS OF THE MARK I TORUS WITH SHELL DIAMETER-TO-THICKNESS RATIOS OF 0, 300, AND 600. THE RESULTS OF THESE ANALYSES SUPPORT EARLIER CONCLUSIONS THAT INCREASED WALL FLEXIBILITY ENHANCES ATTENUATION OF HYDRODYNAMIC LOADS AND FURTHERMORE INDICATE THAT THE MAGNITUDE OF THE ATTENUATION IS ONLY WEAKLY AFFECTED BY THE TOTAL IMPULSE OF THE BUBBLE PRESSURE TIME-HISTORY. (ERA CITATION 05:030624)

63. TI - EFFECTS OF TORUS WALL FLEXIBILITY ON FORCES IN THE MARK I BWR PRESSURE SUPPRESSION SYSTEM: EXTENDED ANALYSES UNDER SRV T-QUENCHER LOADING.
AU - HOLMAN, G. S.; LU, S. C. H.
CS - CALIFORNIA UNIV., LIVERMORE. LAWRENCE LIVERMORE LAB.; DEPARTMENT OF ENERGY.
PU - 11 APR 79; 26P; PC A03/MF A01
NU - CONT. W-7405-ENG-48

64. TI - VIBRATION OF HEAT EXCHANGE COMPONENTS IN LIQUID AND TWO-PHASE CROSS-FLOW
AU - PETTIGREW, M.J.; GORMAN, D.J.
CS - ISSUED BY: ATOMIC ENERGY CANADA LTD., CHALK RIVER, ONTARIO
PU - MAY 1978

65. TI - PIPING RESPONSE TO WATER HAMMER TRANSIENTS INDUCED BY STEAM BUBBLE COLLAPSE.
AU - HURWITZ, W.M.; HUBER, P.W.
PU - FLUID TRANSIENTS AND STRUST INTERACT IN PIPING SYST, PRESENTED AT THE FLUIDS ENG CONF, BOULDER, COLO, JUN 22-24 1981 PUBL BY ASME, NEW YORK, NY, 1981 P 47-53

66. TI - THEROETICAL EVALUATION OF A STEAM BUBBLE COLLAPSE IN THE FEEDWATER SYSTEM OF A NUCLEAR PLANT.
AU - WARREN, ANDREW H.
PU - AICHE SYMP SER N 199 V 76 1980. HEAT TRANSFER - ORLANDO 1980, PAP FROM NATL HEAT TRANSFER CONF, 19TH, ORLANDO, FLA, JUL 27-30 1980, PUBL BY AICHE, NEW YORK, NY, 1980 P 1-13

67. TI - CHECK VALVE CLOSURE BEHAVIOUR; EXPERIMENTAL INVESTIGATION AND SIMULATION IN WATERHAMMER COMPUTER PROGRAMS
AU - KRUISBRINK, A.C.H.; WOOD, P.; GROVE, L.
PU - PROCEEDINGS OF THE 2ND INTERNATIONAL CONFERENCE ON DEVELOPMENTS IN VALVES AND ACTUATORS FOR FLUID CONTROL
Publ: BEDFORD, UK; BHRA
1988; P. 281-300; XII+362 P.; 7 REFS

68. TI - IMPROVED PIPING DESIGN, TESTING CAN REDUCE FLUID TRANSIENT DAMAGE
AU - MIKASINOVIC, M.; MARCUCCI, P.A.
PU - POWER ENG. (USA)
MAY 1987 ; 91(5); P. 36-9 ; 3 REFS

69. TI - THE DYNAMIC BEHAVIOUR OF A FINITE LENGTH STRAIGHT PIPE SUBJECT TO WATERHAMMER. I. FOR SMALL ELASTIC DEFORMATION OF THE PIPE WALL
AU - KOJIMA, E.; SHINADA, M.; NISHIMUTA, S.; MURAYAMA, S.
PU - BULL. JSME (JAPAN)
OCT. 1986 ; 29(256); P. 3352-60 ; 12 REFS

70. TI - WATERHAMMER PRESSURE COMPENSATION IN TURBINE REGULATING SYSTEMS
AU - SHEN ZONGSHU; ZHONG CHENGANG; FU WENYUAN
PU - INT. WATER POWER AND DAM CONSTR. (GB)
AUG. 1986 ; 38(8); P. 25-8 ; 0 REFS

71. TI - STABILITY AND ACCURACY OF WATERHAMMER ANALYSIS
AU - HOLLOWAY, M.B.; CHAUDHRY, M.H.
PU - ADV. WATER RESOUR. (GB)
SEPT. 1985 ; 8(3); P. 121-8 ; 11 REFS

72. TI - WATERHAMMER IN A PRIMARY COOLANT SYSTEM BY CONTROLLING CIRCULATING PUMP REVOLUTION
AU - KATO, E.; SUITA, M.; KAWAMATA, M.; OHMORI, S.
PU - BULL. JSME (JAPAN)
JUNE 1985 ; 28(240); P. 1085-91 ; 14 REFS

73. TI - WATER-HAMMER IN LONG AQUEDUCTS: MATHEMATICAL MODELS AND LABORATORY DATA AU - GRECO, M.; BRUNONE, B.; GOLIA, U.M.; BREBBIA, C.A.; MAKSIMOVIC, C.; RADOJKOVIC, M.
PU - HYDROSOFT '84. HYDRAULIC ENGINEERING SOFTWARE. PROCEEDINGS OF THE INTERNATIONAL CONFERENCE
Publ: AMSTERDAM, NETHERLANDS ; ELSEVIER
1984 ; P. 5/17-29 ; 728 P.; 9 REFS

74. TI - VARIOUS POSSIBILITIES FOR THE SIMULATION OF WATER-HAMMER EFFECTS IN HYDROELECTRIC POWER STATIONS
AU - FASOL, K.H.; SATTLER, H.; BREITENECKER, F.; KLEINERT, W.
PU - SIMULATIONSTECHNIK 2. SYMPOSIUM SIMULATIONSTECHNIK (SIMULATION TECHNIQUES, 2ND SYMPOSIUM)
Publ: BERLIN, GERMANY ; SPRINGER-VERLAG
1984 ; P. 191-6 ; XII+676 P.; 7 REFS

75. TI - MEASURES FOR PREVENTING VIBRATION AND WATERHAMMER IN THE DRAINAGE LINES FOR HEATER SEPARATORS OF SINGLE-PASS BOILERS FOR 300 AND 250 KV POWER UNITS
AU - MALYUTIN, YU.P.; SHVARTSMAN, YA.I.; BELOV, V.A.
PU - ENERGETIK (USSR)
1984 ; NO.11 ; P. 34-6 ; 0 REFS

76. TI - OPTIMUM VALVE OPERATION IN WATERHAMMER
AU - YAMAMOTO, K.
PU - BULL. JSME (JAPAN)
JUNE 1984 ; 27(228); P. 1188-93 ; 5 REFS

77. TI - RESONANCE INTERACTION OF SHOCK WAVES AND HYDRAULIC WAVES
AU - SMIRNOVA, L.P.; SHREIBER, I.R.
PU - AKUST. ZH. (USSR)
MAY-JUNE 1984 ; 30(3); P. 409 ; 0 REFS
Translated in: SOV. PHYS.-ACOUST. (USA)
MAY-JUNE 1984 ; 30(3); 245

78. TI - WATER HAMMER IN THE CIRCULATING PIPE LINE WITH PRESSURE VESSELS
AU - KATO, E.; SUITA, M.; KAWAMATA, M.; YUDA, M.
PU - BULL. JSME (JAPAN)
JUNE 1984 ; 27(228); P. 1182-7 ; 11 REFS

79. TI - PREVENTION AND MITIGATION OF STEAM GENERATOR WATER HAMMER EVENTS IN PWRS
AU - HAN, J.T.; ANDERSON, N.

PU - NUCL. SAF. (USA)
JULY-AUG. 1983 ; 24(4); P. 533-7 ; 14 REFS

80. TI - WATER HAMMER WITH BREAKS IN THE CONTINUITY OF THE LIQUID
AU - GERASHCHENKO, L.S.
PU - FLUID MECH. - SOV. RES. (USA)
MARCH-APRIL 1981 ; 10(2); P. 135-41 ; 11 REFS

81. TI - REGULATION OF KAPLAN AND PIPE TURBINES AND THE IMPACT OF VARIOUS OPERATING REGIMES ON THE WATER HAMMER
AU - MIRJANIC, D.
PU - ELEKTROPRIVREDA (YUGOSLAVIA)
NOV.-DEC. 1982 ; 35(11-12); P. 343-8 ; 0 REFS

82. TI - RESONANT WATERHAMMER: A CASE STUDY
AU - PEREZ, H.
PU - INT. WATER POWER AND DAM CONSTR. (GB)
APRIL 1982 ; 34(4); P. 42-3 ; 0 REFS

83. TI - EXPERIMENTAL STUDY OF THE ATTENUATION OF A WATER-HAMMER PRESSURE WAVE
AU - MAGDALINSKAYA, I.V.; ROZENBERG, G.D.
PU - DOKL. AKAD. NAUK SSSR
DEC. 1980 ; 255(4-6); P. 814-16 ; 2 REFS
Translated in: SOV. PHYS.-DOKL. (USA)
DEC. 1980 ; 25(12); 973-4

84. TI - COMPUTER SIMULATED WATERHAMMER IN PIPE NETWORKS
AU - KOCH, B.
PU - UKSC 81. PROCEEDINGS OF THE 1981 UKSC CONFERENCE ON COMPUTER SIMULATION Publ: GUILDFORD, SURREY, ENGLAND ; WESTBURY HOUSE
1981 ; P. 214-23 ; XII+451 P.; 3 REFS

85. TI - SEMI-DISCRETE AND FULLY DISCRETE FINITE-ELEMENT METHODS WITH PENALTY FOR THE NUMERICAL SOLUTION OF THE WATERHAMMER PROBLEM
AU - NASSIF, N.R.; PINI, F.
PU - SIAM J. NUMER. ANAL. (USA)
FEB. 1981 ; 18(1); P. 111-28 ; 8 REFS

86. TI - WATERHAMMER SOLUTION BY PROGRAMMABLE CALCULATOR
AU - ANDERSON, A.
PU - INT. WATER POWER AND DAM CONSTR. (GB)
NOV. 1980 ; 32(11); P. 53-9 ; 17 REFS

87. TI - KAPLAN TURBINE INCIDENTS AND REVERSE WATERHAMMER
AU - PEJOVIC, S.; KRSMANOVIC, L.; GAJIC, A.; OBRADOVIC, D.
PU - INT. WATER POWER AND DAM CONSTR. (GB)
AUG. 1980 ; 32(8); P. 36-40 ; 3 REFS

88. TI - WATER HAMMER PHENOMENA IN THERMAL POWER STATION FEED WATER SYSTEMS
AU - WILKINSON, D.H.; DARTNELL, L.M.
PU - PROC. INST. MECH. ENG. (GB)
MARCH 1980 ; VOL.194 ; P. 17-25 ; 3 REFS

89. TI - WATERHAMMER STUDIES OF POWER/DESAL PLANTS COOLING WATER SYSTEM WITH COMMON DISCHARGE CONDUIT
AU - HSIEH, W.S.; STANGE, J.R.
PU - DESALINATION (NETHERLANDS)
OCT. 1979 ; 31(1-3); 183-4

90. TI - A COMPUTER SIMULATION OF WATER HAMMER IN PIPELINE NETWORKS
AU - KOIDA, N.U.
PU - IZV. VUZ ENERG. (USSR)
APRIL 1978 ; NO.4 ; 97-100

91. TI - NUMERICAL TREATMENT OF WATER-HAMMER IN BIFURCATING PIPE-LINES
AU - MECHOSO, C.R.
URUGUAY
PU - BOL. FAC. ING. AND AGRIMENSURA MONTEVIDEO (URUGUAY)
SEPT. 1974 ; 13(1); 51-67

92. TI - THE SURGE TANK-A DEVICE FOR CONTROLLING WATER HAMMER. II
AU - MOSONYI, E.; SETH, H.B.S.
PU - INT. WATER POWER AND DAM CONSTR. (GB)
MARCH 1975 ; 27(3); 119-23

93. TI - REVERSE WATER HAMMER IN TURBINE DRAFT TUBES II
AU - JORDAN, V.
PU - INT. WATER POWER AND DAM CONSTR. (GB)
MARCH 1975 ; 27(3); 116-18

94. TI - STUDY OF WATERHAMMER USING AN ELECTRICAL ANALOGUE
AU - DELPUY, R.
PU - AN. MEC. AND ELECTR. (SPAIN)
JAN.-FEB. 1975 ; 52(1); 22-35

95. TI - WATER HAMMER AND ELECTRICALLY OPERATED VALVE CONTROL
AU - SHIKATA, M.
PU - SHIMADZU REV. (JAPAN)
1974 ; 31(4); 171-8

96. TI - THE SURGE TANK-A DEVICE FOR CONTROLLING WATER HAMMER. I
AU - MOSONYI, E.; SETH, H.B.S.
PU - INT. WATER POWER AND DAM CONSTR. (GB)
FEB. 1975 ; 27(2); 69-74

97. TI - COMPUTER SOLUTIONS TO WATER-HAMMER PROBLEMS USING THE METHOD OF CHARACTERISTICS
AU - SATTLER, H.; STROHMER, F.
PU - WATER POWER (GB)
SEPT. 1974 ; 26(9); 322-7

98. TI - THE ANALYSIS OF WATERHAMMER EFFECTS IN WATER DISTRIBUTION SYSTEMS
AU - STACK, R.J.
PU - COMPUTERS IN ENGINEERING
Publ: SYDNEY, AUSTRALIA ; INSTN. ENGRS., AUSTRALIA
1974 ; 211-15

99. TI - WATER-HAMMER ANALYSIS FOR A UNIFILAR COMPLEX PIPE-SYSTEM
AU - BELIK, N.P.; SEMENOV, V.A.; ZEL'DINA, Z.A.
PU - GIDROMEKHANIKA (USSR)
1973 ; NO.23 ; 77-83

100. TI - RESONANT WATER HAMMER INDUCED BY VIBRATIONS IN A SPHERICAL VALVE
AU - JORDAN, V.
PU - WATER POWER (GB)
MAY 1973 ; 25(5); 171-8

101. TI - COMBINED SURGE TANK AND WATER-HAMMER ANALYSIS BY DIGITAL COMPUTER
AU - MARTIN, C.S.; JACKSON, H.C.
PU - WATER POWER (GB)
APRIL 1972 ; 24(4); 123-9

102. TI - WATER-HAMMER WHEN CLOSING THE BOTTOM GATE OF A HYDRAULIC TURBINE
AU - BORODINA, L.K.
PU - GIDROTEKH. STROIT. (USSR)
1971 ; NO. 2 ; 34-5

103. TI - THE PROBLEM OF WATER-HAMMER IN THE INNERFRAQANT HYDRO-ELECTRIC SCHEME
AU - TANZAMANN, W.
PU - OSTERR. Z. ELEKTWIRTSCH (OZE) (AUSTRIA)
OCT. 1969 ; 22(10); 507-10

104. TI - HYDROAKUSTISCHER PULSSTRAHLERZEUGER. (HYDRO-ACOUSTIC PULSE JET GENERATOR).
AU - UNRAU, A.; MEIER, G.E.A.
PU - APR 87; 26P; IN GERMAN,MAX-PLANCK-INSTITUT FUER STROEMUNGSFORSCHUNG. BERICHT, NO. 7/1987; PC E07
AB - APPARATUS WAS EXAMINED WHICH, WHEN CONNECTED TO A LOW PRESSURE WATER PIPE, GENERATES A NON-STEADY HIGH PRESSURE WATER JET. THIS PULSE JET GENERATOR USES THE PHENOMENON OF WATER HAMMER, WHICH OCCURS IN QUICK CHANGES OF FLOW IN PIPES, TO GENERATE A PULSATING WATER JET AT HIGH PRESSURE. THE PULSE JET GENERATOR CONSISTS MAINLY OF A PIPE, A VALVE HEAD WITH A VALVE, A SPRING AND A RESERVOIR. THE JET PRODUCED IS THE RESULT OF THE COLLABORATION OF A NONSTEADY VALVE. THE PRESSURE OF THE JET DEPENDS ON THE SPECIFIC ACCOUSTIC IMPENDANCE RHO A SUB T (A SUB T = SPEED OF SOUND IN THE LIQUID IN THE PIPE RHO DENSITY OF LIQUID) AND THE DIFFERENCE BETWEEN THE SPEEDS OF FLOW IN THE PIPE BEFORE AND AFTER THE WATER HAMMER. PRESSURES UP TO 40 BAR COULD BE INTRODUCED HERE WORKS MORE EFFECIENTLY THAN PREVIOUSLY EXISTING VERSIONS. PRESSURE SIGNALS IN THE PULSE JET GENERATOR WERE RECORDED WITH PIEZO-ELECTRIC PRESSURE TRANSDUCERS AND WERE EXAMINED. MAXIMUM SPEED PHOTOGRAPHS WERE TAKEN OF THE JET AND ITS PRESSURE WAS MEASURED. THE RESULTS AGREE WITH THEORETICAL CALCULATIONS. (ORIG.). (COPYWRIGHT (C) 1988 BY FIZ. CITATION NO. 88:081707).

105. TI - EIN HYDROAKUSTISCHER PULSSTRAHLERZEUGER (HYDROACOUSTIC PULSATING JET GENERATOR).
AU - UNRAU, A.; MEIER, G. E. A.
CS - MAX-PLANCK-INSTITUTE, GOETTINGEN, GERMANY
PU - APR 87; 27P; TEXT IN GERMAN; PC A03/MF A01

AB - A HIGH PRESSURE TURBULENT JET GENERATOR CONNECTED TO A LOW PRESSURE HYDRAULIC TUBE IS STUDIED TO INVESTIGATE WATER HAMMER IN TUBES WITH FAST FLOW VARIATIONS, GENERATING HIGH PRESSURE PULSATING WATER JETS. THE PULSATING JET GENERATOR CONSISTS OF A TUBE, A HYDRAULIC VLAVE, A SPRING, AND A WATER CONTAINER. THE JET IS THE EFFECT OF THE COMBINATION OF TURBULENT PIPEFLOW WITH A VALVE FOR FLOW NOZZLE. THE JET PRESSURE DEPENDS ON SPECIFIC OSCILLATION IMPEDANCE AND FLOW VELOCITY VARIATIONS. FOR INLET PRESSURE OF 0.5 TO 2 BAR THE PRESSURE RISES TO 40 BAR. THE DESCRIBED PULSATING JET GENERATOR IS MORE EFFECTIVE THAN THE EARLIER MODEL. A PIEZOELECTRIC PRESSURE CONTROLLER IS USED TO REGISTER PRESSURE SIGNALS AND HIGH SPEED PHOTOS ARE MADE OF THE JET. TEST RESULTS ARE CONSISTENT WITH THEORETICAL CALCULATION.

106. TI - COMPUTER-AIDED EVALUATION OF WATER HAMMER PROTECTION IN FLUID FLOW SYSTEMS.
AU - ANSPACH, E.; HOEHN, W.; KNAPP, P.; SEMLER, F.
CS - KLEIN, SCHANZLIN UND BECKER, GRANKENTHAL/PFALZ, GERMANY
PU - MAR 87; 13P; IN ITS KLEIN, SCHANZLIN, AND BECKER (KSB) TECHNICAL REPORTS, N21 P3-15; (ORDER AS N87-28841/1, PC A04/MF A01)
AB - A COMPUTER PROGRAM BASED ON THE MOMENTUM AND CONTINUITY EQUATIONS AS SIMULTANEOUS PARTIAL DIFFERENTIAL EQUATIONS WAS DEVELOPED TO AID IN THE DESIGN OF FLUID FLOW SYSTEMS AGAINST WATER HAMMER EFFECTS. ACCORDING TO THE METHOD OF CHARACTERISTICS THE EQUATIONS ARE TRANFORMED INTO FINITE DIFFERENCE EQUATIONS AND ARE NUMERICALLY INTEGRATED. METHODS OF WATER HAMMER PROTECTION ARE SUMMARIZED. EXAMPLES IN WHICH THE RESULTS OF CALCULATIONS, ESPECIALLY THE PEAK VALUES OF PRESSURE EXCURSIONS, ARE COMPARED WITH FIELD MEASUREMENTS OF ACTUAL INSTALLATIONS ARE DESCRIBED. THE ECONOMY AND RELIABILITY OF INVESTIGATIONS OF AND SOLUTIONS TO WATER HAMMER PROBLEMS ARE DISCUSSED.

107. TI - KLEIN, SCHANZLIN, AND BECKER (KSB) TECHNICAL REPORTS, NUMBER 21.
CS - KLEIN, SCHANZLIN UND BECKER A.G., FRANKENTHAL/PFALZ (GERMANY, F.R.).;
064120000 KX307928
PU - MAR 87; 62P; PC A04/MF A01

108. TI - STRUCTURAL DYNAMICS METHODS OF CALCULATING WATER HAMMER IN PIPEWORK.
AU - MEDER, G.; NGUYEN-TUONG, B.
CS - CENTRAL ELECTRICITY GENERATING BOARD, LONDON, ENGLAND
PU - 1984; 34P; U.S. SALES ONLY. PORTIONS OF THIS DOCUMENT ARE ILLEGIBLE IN MICROFICHE PRODUCTS; TRANSLATED FROM VGB KRAFTWERKSTECH.; 64: NO. 2,
119-132(1984); PC A03/MF A01
AB - VARIOUS METHODS USED IN STRUCTURAL DYNAMICS FOR DETERMINATION OF THE DYNAMIC STRESSING OF PIPEWORK AS A RESULT OF WATER HAMMER FORCES HAVE BEEN COMPARED. IN ADDITION TO THE MATHEMATICALLY ACCURATE METHODS SUCH AS 'DIRECT INTEGRATION' AND 'MODAL TIME HISTORY METHOD', APPROXIMATION METHODS SUCH AS 'SPECTRUM METHOD' AND 'EQUIVALENT STATIC METHOD' HAVE BEEN DISCUSSED. SPECIAL ATTENTION WAS PAID TO THE BASIC SOLUTION BEHAVIOUR OF THE INDIVIDUAL METHODS. TAKING SELECTED PIPEWORK FROM POWER STATION PRACTICE AS AN EXAMPLE, THE PROBLEMS ASSOCIATED WITH APPLICATION OF THE METHODS HAVE BEEN

EXPLAINED AND THE CONFIDENCE RANGE OF THE DYNAMIC RESULTS DISCUSSED. AIM OF THE WORK IS TO PROVIDE A DECISION-MAKING AID FOR SELECTION OF A STRUCTURAL DYNAMICS METHOD OF CALCULATING WATER HAMMER IN PIPEWORK. (ERA CITATION 11:013195)

109. TI - CHECK VALVE CLOSURE TRANSIENTS AND THE RETRAN CODE.
AU - KOBUSSEN, J. A.; MYLONAS, R.; ZHENG, W. X.
CS - EIDGENDESSISCHES INSTITUTE, WUERENLINGEN, SWITZERLAND
PU - MAR 84; 21P; U.S. SALES ONLY; PC A02/MF A01
AB - THE MAIN FEEDWATER LINE SUPPLYING A STEAM GENERATOR OF A PWR USUALLY CONTAINS A CHECK VALVE. IN CASE OF A FEEDWATER PIPE RUPTURE, THE CHECK VALVE SHOULD CLOSE AS SOON AS POSSIBLE, IN ORDER TO ALLOW A MINIMAL LOSS OF WATER FROM THE STEAM GENERATOR ONLY. ON THE OTHER HAND, A FAST CLOSING VALVE CAN PRODUCE SEVERE PRESSURE TRANSIENTS (WATERHAMMER) IN THE FEEDWATER LINE LEADING TO THE STEAM GENERATOR. TO DIMINISH THE SEVERITY OF THE PRESSURE TRANSIENTS IT HAS BEEN SUGGESTED THAT THE DAMPED CHECK VALVE MIGHT BE AN ALTERNATIVE WHEN EQUIPING THE MAIN FEEDWATER LINE OF A PWR PLANT. A SUBROUTINE DESCRIBING THE CONVENTIONAL SWING TYPE AND THE DAMPED PLUG TYPE CHECK VALVE HAS BEEN DEVELOPED AND IMPLEMENTED INTO THE RETRAN CODE. THE CHECK VALVE MODEL WAS TESTED ON A POSTULATED FEEDLINE RUPTURE OF THE WESTINGHOUSE DESIGNED KKB (KERNKRAFTWERK BEZNAU) PLANT. THE RETRAN CALCULATIONS PERFORMED WITH THE CONVENTIONAL SWING TYPE CHECK VALVE, AS ACTUALLY BUILT IN THE KKB PLANT, SHOW A VERY GOOD AGREEMENT WITH EARLIER RESULTS OBTAINED WITH THE ITCH-MULTIFLEX CODE. SHOULD, ON THE OTHER HAND, THE KKB CHECK VALVE BE REPLACED BY A PROPERLY DESIGNED DAMPED PLUG TYPE CHECK VALVE, A RETRAN ANALYSIS SHOWS THAT THE PRESSURE PEAKS CAN BE SUPPRESSED ALMOST COMPLETELY. (ATOMINDEX CITATION 16:064788)

110. TI - PRACTICE; CRITERIA; PROVISIONS; MATHEMATICAL DESCRIPTIONS: EXAMPLES.
AU - WIJDIEKS, J.
CS - WATERLOOPKUNDIG LAB., DELFT, NETHERLANDS
PU - JUN 83; 49P; PC A03/MF A01
AB - WATERHAMMER IS DEFINED AS THE APPEARANCE OF PRESSURE CHANGES IN CLOSED CONDUITS CAUSED BY VELOCITY CHANGES WITH TIME OF THE FLOW. THEREFORE WATERHAMMER MAY OCCUR IN ALL KINDS OF PIPELINGS IN WHICH FLOW CHANGES OCCUR OVER TIME: LONG OF SHORT PIPELINES FOR OIL, SEWAGE, DRINKING WATER, COOLING WATER, SLURRY, COAL SLURRY, CHEMICALS, AND IN FRESH WATER OF CITY HEATING NETWORKS. THE PHENOMENON OF WATERHAMMER IS DISCUSSED HEREIN. SPECIFIC PARAMETERS ADDRESSED INCLUDE: THE PRACTICAL CAUSES OF WATERHAMMER, CAVITATION FLOW, OVERPRESSURE, VAPOR PRESSURES, BULK MODULUS, CONTINUOUS AND DISCONTINUOUS FLOW, AND PROVISIONS TO PREVENT WATERHAMMER, CALCULATION OF WATERHAMMER IS PRESENTED ALONG WITH A MATHEMATICAL DESCRIPTION THEREOF. HYDRAULIC EQUIPMENT (VALVES, PUMPS, SURGE TOWERS) IS ALSO DISCUSSED.

111. TI - CONTROL AND SUPPRESSION OF PRESSURE SURGES IN PIPELINES AND TUNNELS.
AU - THORLEY, A. R. D.; ENEVER, K. J.
CS - CONSTRUCTION INDUSTRY RESEARCH AND INFORMATION ASSOCIATION, LONDON (ENGLAND).; 076547000
PU - C1979; 116P; ALSO PUB. IN ISSN-0305-408X; PC E20/MF E20

AB - THE REPORT DESCRIBES THE PHENOMENON OF PRESSURE SURGE (I.E. WATER HAMMER) AND THE CIRCUMSTANCES IN WHICH IT CAN ARISE. SOME GUIDANCE IS OFFERED TO ENABLE THE DESIGN ENGINEER TO DECIDE WHETHER OF NOT IT IS LIKELY TO BE DANGEROUS, FOLLOWED BY A DISCUSSION OF VARIOUS METHODS OF SURGE SUPPRESSION AND CONTROL. MANY DESIGN SITUATIONS OCCUR WHERE IT IS ADEQUATE TO USE APPROXIMATE METHODS OF ANALYSIS, EITHER ON THEIR OWN, OR BEFORE USING MORE SOPHISTICATED METHODS SUCH AS COMPUTER-AIDED NUMERICAL TECHNIQUES. SOME OF THE MORE ACCEPTABLE APPROXIMATE METHODS ARE DESCRIBED, AND SEVERAL WORKED EXAMPLES ARE INCLUDED. THE BASIC THEORY OF PRESSURE SURGE IS OUTLINED, TOGETHER WITH GRAPHICAL AND NUMERICAL TECHNIQUES FOR SOLVING THE RESULTING PARTIAL DIFFERENTIAL EQUATIONS.

112. TI - ANALYSIS TOOL FOR PREDICTING THE TRANSIENT HYDRODYNAMICS RESULTING FROM THE RAPID FILLING OF VOIDED PIPING SYSTEMS.
AU - WILLIAMSON, R. L.
CS - EG AND G IDAHO, INC., IDAHO FALLS.; 046580000 9507781
PU - FEB 79; 180P; PC A09/MF A01
AB - AN ANALYSIS TOOL IS CONSTRUCTED FOR THE PURPOSE OF PREDICTING THE TRANSIENT HYDRODYNAMICS RESULTING FROM THE RAPID FILLING OF VOIDED PIPING SYSTEMS. THE BASIC REQUIREMENTS OF SUCH AN ANALYSIS TOOL ARE ESTABLISHED, AND DOCUMENTATION IS PRESENTED FOR SEVERAL FLUID TRANSIENT COMPUTER CODES WHICH WERE CONSIDERED FOR THE TOOL. THE CODE MODIFICATIONS NECESSARY TO MEET THE ANALYSIS TOOL REQUIREMENTS ARE DESCRIBED. TO TEST THE COMPUTATIONAL CAPABILITY OF THE ANALYSIS TOOL A VERIFICATION PROBLEM IS CONSIDERED AND THE RESULTS REPORTED. THESE RESULTS SERVE ONLY TO DEMONSTRATE THE APPLICABILITY OF THE ANALYSIS TOOL TO THIS TYPE OF PROBLEM; THE CODE HAS NOT BEEN VALIDATED BY COMPARISON WITH EXPERIMENT. DOCUMENTATION IS PROVIDED FOR A BRIEF SENSITIVITY STUDY INVOLVING THE SAMPLE PROBLEM. ADDITIONAL ANALYSIS TOOL INFORMATION, AS WELL AS DETAILED SAMPLE PROBLEM RESULTS ARE INCLUDED IN THE FORM OF APPENDICES. (ERA CITATION 05:003072)

113. TI - VIBRATION PHENOMENA IN LARGE SCALE PRESSURE SUPPRESSION TESTS.
AU - AUST, E.; BOETTCHER, G.; KOLB, M.; SATTLER, P.; VOLLBRANDT, J.
CS - GKSS - FORSCHUNGSZENTRUM GEESTHACHT G.M.B.H., GEESTHACHT-TESPERHUDE (GERMANY, F.R.); 072705000 2818600
PU - 1982; 19P; U.S. SALES ONLY; INTERNATIONAL CONFERENCE ON VIBRATIONS IN NUCLEAR PLANTS, KESWICK, UK, 11 MAY 1982; PC A02/MF A01
AB - STRUCTURE AND FLUID VIBRATION PHENOMENA (ACCELERATION, STRAIN, PRESSURE, LEVEL) WERE OBSERVED DURING BLOW-DOWN EXPERIMENTS SIMULATING A LOCA IN THE GKSS FULL SCALE MULTIVENT PRESSURE SUPPRESSION TEST FACILITY. THE PAPER DESCRIBES FIRST THE SOURCE RELATED EXCITATIONS DURING THE TWO REGIMES OF CONDENSATION OSCILLATION AND OF CHUGGING, AND DEALS THEN WITH THE RESPONSE VIBRATIONS OF THE FACILITY'S WETWELL. MODAL ANALYSES OF THE WETWELL WERE RUN USING EXCITATION BY HAMMER AND BY SHAKER IN ORDER TO SEPARATE PHENOMENA THAT ARE PARTICULAR TO THE GKSS FACILITY FROM MORE GENERAL ONES, I.E. PHENOMENA SPECIFIC TO THE FLUID RELATED PARAMETERS OF BLOWDOWN AND TO THE GEOMETRY OF THE VENT PIPES ONLY. THE LOWEST PERIODICITIES AT ABOUT 12 AND 16 HZ STEM FROM THE VENT ACOUSTICS. A FREQUENCY OF ABOUT 36 TO 38 HZ PROMINENT DURING CHUGGING SEEMS TO RESULT FROM THE LOWEST LOCAL MODELS OF TWO OF THE

WETWALL'S WALLS WHEN COUPLED BY THE WETWELL POOL. FURTHER PEAKS FOUND DURING BLOWDOWN IN THE SPECTRA OF SIGNALS AT HIGHER FREQUENCIES CORRESPOND TO GLOBAL VIBRATION MODES OF THE WETWELL. (ERA CITATION 08:020693)

114. TI - INITIATION OF WATER HAMMER IN HORIZONTAL OR NEARLY-HORIZONTAL PIPES CONTAINING STEAM AND SUBCOOLED WATER.
AU - BJORGE, ROBERT W.
CS - MASSACHUSETTS INST. OF TECH., CAMBRIDGE. ENERGY LAB.; 001450229
PU - FEB 83; 160P; FINAL REPT; SPONSORED IN PART BY BOSTON EDISON CO., MA., AND NORTHEAST UTILITIES SERVICE CO., HARTFORD, CT; PC A08/MF A01
AB - WATER SLUG FORMATION IN A STRATIFIED COUNTERCURRENT FLOW OF STEAM AND SUBCOOLED WATER IN A HORIZONTAL OR NEARLY HORIZONTAL PIPE TRAPS A LARGE STEAM BUBBLE, WHICH THEN COLLAPSES RAPIDLY AND CAUESE A WATER HAMMER. THIS WATER HAMMER INITIATING MECHANISM HAS BEEN STUDIED EXPERIMENTALLY AND ANALYTICALLY. WATER SLUG FORMATION IN A STRATIFIED COUNTERCURRENT FLOW OF STEAM AND SUBCOOLED WATER IN A HORIZONTAL OR NEARLY HORIZONTAL PIPE TRAPS A LARGE STEAM BUBBLE, WHICH THEN COLLAPSES RAPIDLY AND CAUSES A WATER HAMMER. THIS WATER HAMMER INITIATING MECHANISM HAS BEEN STUDIED EXPERIMENTALLY AND ANALYTICALLY.

115. TI - THE EFFECT OF AXIAL TUBE ELASTICITY ON WATER HAMMER PRESSURE.
AU - SZUMOWSKI, A. P.
CS - MAX-PLANCK-INST. FUER STROEMUNGSFORSCHUNG, GOETTINGEN (GERMANY, F.R.).; 017448000 MN850278
PU - JUL 80; 24P; PC A02/MF A01

116. TI - AN EXTENSION OF THE THEORY OF WATER HAMMER
AU - SKALAK, RICHARD
CS - COLUMBIA UNIVERSITY, NEW YORK COLLEGE OF PHYSICIANS & SURGEONS, USA
PU - MAR 55; 10P; DISTRIBUTION LIMITATION NOW REMOVED. NOTE: ONLY 35MM MICROFILM IS AVAILABLE. NO MICROFICHE; MF A01

117. TI - REFLECTION AND TRANSMISSION OF FLUID TRANSIENTS AT AN ELBOW.
AU - VALENTIN, R. A.; PHILLIPS, J. W.; WALKER, J. S.
PU - 1979; 16P; INTERNATIONAL CONFERENCE ON STRUCTURAL MECHANICS IN REACTOR TECHNOLOGY, BERLIN, F.R. GERMANY, 13 AUG 1979; PC A02/MF A01

118. TI - LOFT LOCA: WHAM6 MODEL AND CODE APPLICATION.
AU - BERTA, V. T.
CS - IDAHO NATIONAL ENGINEERING LAB., IDAHO FALLS.; DEPARTMENT OF ENERGY.
PU - 27 JUL 78; 40P; PORTIONS OF DOCUMENT ARE ILLEGIBLE; PC A03/MF A01

119. TI - INVESTIGATION INTO CAVITATION IN A PROTOTYPE PIPELINE CAUSED BY WATER HAMMER.
AU - PROVOOST, G. A.
CS - DELFT HYDRAULICS LAB. (NETHERLANDS).
PU - NOV 76; 20P; CONF-PRESENTED AT THE 2D INTERN. CONF. ON PRESSURE SURGES, LONDON, 22-24 SEP. 1976; PC A02/MF A01

120. TI - PRESSURIZED WATER-REACTOR FEEDWATER PIPING RESPONSE TO WATER HAMMER.
AU - ARTHUR, D.
CS - CALIFORNIA UNIV., LIVERMORE. LAWRENCE LIVERMORE LAB.; DEPARTMENT OF ENERGY.
PU - MAR 78; 37P; PC A03/MF A01

121. TI - REVIEW OF LITERATURE ON THE ASYMMETRIC COLLAPSE OF VAPOR BUBBLES.
AU - FREMD, R.; FROEHLICH, G.
CS - STUTTGART UNIV. (WEST GERMANY). INST. FUER KERNENERGETIK UND ENERGIESYSTEME.
PU - JUN 77; 36P; AVAILABLE IN MICROFICHE ONLY. U.S. SALES ONLY; ; MF A01

122. TI - ANALYSIS OF THE METHOD OF STREETER AND WYLIE FOR MULTIDIMENSIONAL WAVE PROPAGATION.
AU - COLE, R. K. JR
CS - SANDIA LABS., ALBUQUERQUE, N.MEX.; DEPARTMENT OF ENERGY.
PU - JUL 77; 21P; MF A01

123. TI - INVESTIGATION OF PRESSURE TRANSIENT PROPAGATION IN PRESSURIZED WATER REACTOR FEEDWATER LINES.
AU - SUTTON, S. B.
CS - CALIFORNIA UNIV., LIVERMORE. LAWRENCE LIVERMORE LAB.; ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION.
PU - 22 JUL 77; 70P; PC A04/MF A01

124. TI - HAMOC: A COMPUTER PROGRAM FOR FLUID HAMMER ANALYSIS.
AU - JOHNSON, H. G.
CS - HANFORD ENGINEERING DEVELOPMENT LAB., RICHLAND, WASH.; ENERGY RESEARCH AND DEVELOPMENT ADMINISTRATION.
PU - DEC 75; 163P

125. TI - PULSE PROPAGATION IN FLUID-FILLED TUBES.
AU - WALKER, J. S.; PHILLIPS, J. W.
CS - ILLINOIS UNIV. AT URBANA-CHAMPAIGN. DEPT. OF THEORETICAL AND APPLIED MECHANICS.; NATIONAL SCIENCE FOUNDATION, WASHINGTON, D.C.
PU - NOV 75; 30P

126. TI - THE EFFECT OF FREE GASES ON PRESSURE TRANSIENTS.
AU - MARTIN, C. S.; PADAMANABHAN, M.; WIGGERT, D. C.
CS - GEORGIA INST. OF TECH., ATLANTA. SCHOOL OF CIVIL ENGINEERING.; NATIONAL SCIENCE FOUNDATION, WASHINGTON, D.C. DIV. OF ENGINEERING.; MICHIGAN STATE UNIV., EAST LANSING.
PU - JUN 76; 228P; FINAL REPT. 1 JUN 73-31 MAY 76; PREPARED IN COOPERATION WITH MICHIGAN STATE UNIV., EAST LANSING

127. TI - ESTIMATED TURBOPUMP OPERATION DURING NRX/EST FLOW SHUTDOWN FROM FULL POWER.
AU - NISHIOKA, T.; PFREMMER, R. D.
CS - AEROJET-GENERAL CORP., SACRAMENTO, CALIF.
PU - 28 MAR 66; 9P

128. TI - CAVITATION CAUSED BY WATER HAMMER IN HORIZONTAL PIPELINES.
AU - KALKWIJK, J. P. T.; KRANENBURG, C.; VREUGDENHIL, C. B.; DEVRIES, A. H.

CS - TECHNISCHE HOGESCHOOL, DELFT (NETHERLANDS). LAB. OF FLUID MECHANICS.
PU - MAR 72; 38P; SUBM-PREPARED JOINTLY WITH WATERLOOPKUNDIG LAB

129. TI - PRESSURE WAVE TRANSMISSION IN A FLUID CONTAINED IN A PLASTICALLY DEFORMING PIPE.
AU - FOX, G. L.; MERCKX, K. R.
CS - HANFORD ENGINEERING DEVELOPMENT LAB., RICHLAND, WASH.
PU - JUN 73; 26P

130. TI - PRESSURE WAVE TRANSMISSION IN A FLUID CONTAINED IN A PLASTICALLY DEFORMING PIPE.
AU - FOX, G. L. JR.; STEPNEWSKI, D. D.
CS - HANFORD ENGINEERING DEVELOPMENT LAB., RICHLAND, WASH. (USA).
PU - DEC 73; 25P

131. TI - BROWNS FERRY NUCLEAR POWER STATION, UNIT 1. CORRECTIVE ACTION TAKEN AFTER INSPECTION OF DECEMBER 14 AND 20--21, 1972.
CS - TENNESSEE VALLEY AUTHORITY, CHATTANOOGA.
PU - 2 MAY 73; 29P

132. TI - TRANSIENTS IN COOLING WATER SYSTEMS OF THERMAL POWER PLANTS, PART 2.
AU - SAFWAT, H. H.
CS - WATERLOOPKUNDIG LABORATORIUM, DELFT (NETHERLANDS).
PU - APR 72; 160P; PH.D. THESIS

133. TI - TRANSIENTS IN COOLING WATER SYSTEMS OF THERMAL POWER PLANTS, PART 1.
AU - SAFWAT, H. H.
CS - WATERLOOPKUNDIG LABORATORIUM, DELFT (NETHERLANDS).
PU - APR 72; 144P; PH.D. THESIS

134. TI - QUAD-CITIES STATION, UNIT 1. ABNORMAL OCCURRENCE 1-72-4. WATER HAMMER DAMAGED SPRAY SYSTEM.
CS - COMMONWEALTH EDISON CO., CORDOVA, ILL.
PU - 5 APR 72; 1P

135. TI - EFFECT OF PIPELINE JUNCTIONS ON WATER HAMMER SURGES.
AU - WOOD, DON J.; CHAO, SHEN P'ENG
CS - KENTUCKY UNIV LEXINGTON DEPT OF CIVIL ENGINEERING
PU - 13 AUG 70; 21P; AVAILABILITY: PUB. IN PROCEEDINGS OF THE AMERICAN SOCIETY OF CIVIL ENGINEERS, V97 NTE3 P441-457 AUG 71

136. TI - WATER HAMMER AND SURGE TANKS.
AU - ARONOVICH, G. V.; KARTVELISHVILI, N. A.; LYUBIMTSEV, YA. K.
CS - NATIONAL SCIENCE FOUNDATION, WASHINGTON, D.C. SPECIAL FOREIGN CURRENCY SCIENCE INFORMATION PROGRAM.
PU - 1970; 209P*; TRANS. OF MONO. GIDRAVLICHESKII UDAR I URAVNITELNYE REZERVUARY, MOSCOW, 1968 247P, BY D. LEDERMAN; PC A10 MF A01

137. TI - ANALYSIS OF CHECK VALVE DISC MOTION DURING A FLOW TRANSIENT.
AU - FULS, G. M.
CS - WESTINGHOUSE ATOMIC POWER DIV PITTSBURGH PA; 375400
PU - DEC 62; 45P; TECHNICAL MEMO; PREVIOUSLY ANNOUNCED AS WAPD-TM-323;

PC A03 MF A01

138. TI - ANALOG ANALYSIS OF FLOW REVERSAL AND WATER-HAMMER PRESSURE IN A TYPICAL CLOSED AARR HYDRAULIC RABBIT-TUBE FACILITY.
AU - ROHDE, RAYMOND R.; WINIECKI, ALAN L.
CS - ARGONNE NATIONAL LAB., ILL.; 033 550
PU - AUG 67; 23P; PC A02 MF A01

139. TI - A METHOD OF CHARACTERISTICS SOLUTION FOR THE EQUATIONS GOVERNING THE UNSTEADY FLOW OF LIQUIDS IN CLOSED SYSTEMS.
AU - KRANE, K. J.; REIFF, A.
CS - OPERATIONS RESEARCH, INC., SANTA MONICA, CALIF.
PU - 30 AUG 66; 126P; PC A07 MF A01

140. TI - TRANSIENT PRESSURE RESPONSE IN A FLUID SYSTEM AS A VIBRATING VALVE CLOSES.
AU - PONDER, C. A. JR
CS - NATIONAL AERONAUTICS AND SPACE ADMINISTRATION, MARSHALL SPACE FLIGHT CENTER, HUNTSVILLE, ALA.
PU - 5 FEB 65; 58P; PC A04 MF A01

141. TI - EXPERIMENTAL AND ANALYTICAL STUDIES ON WATERHAMMER GENERATED BY THE CLOSING OF CHECK VALVES.
AU - HUET, J.L.; GARCIA, J.L.; COPPOLANI, P.; ZIEGLER, B. (CEA-CEN CADARACHE, IRDI/DRE/STRE, ST-PAUL-LEZ-DURANCE (FRANCE)). WITTMANN, F.H.
PU - P. 25-30. STRUCTURAL MECHANICS IN REACTOR TECHNOLOGY. ACCORD, MA (USA). A.A. BALKEMA PUBLISHERS, 1987.
AB - A DOUBLE-GUILLOTINE RUPTURE ON A WATER LINE UPSTREAM FROM A CHECK VALVE AND THE PRESSURE VESSEL ON THE DOWNSTREAM SIDE. SUCCESSIVELY FOLLOWING PHENOMENA OCCUR: - DECREASE THEN REVERSAL OF THE FLOW, - CLOSING OF THE CHECK VALVE WITH IMPACT OF THE PLUG ON ITS SEAT, - WATERHAMMER PROPAGATING IN THE PIPE DOWNSTREAM FROM THE CHECK VALVE. THE COMMISARIAT A L'ENERGIE ATOMIQUE (C.E.A.) FRAMATOME AND ELECTRICITE DE FRANCE (E.D.F.) HAVE UNDERTAKEN A JOINT PROGRAM IN ORDER TO: - INVESTIGATE THE BEHAVIOUR OF THE CHECK VALVE IN THE EVENT OF A SUDDEN CLOSURE, - EVALUATE THE PRESSURE AND FLOW TRANSIENT IN THE LINE. THE PROGRAM INCLUDES: - JULL SCALE TESTS IN TWO LOOPS, CLAUDIA (C.E.A.) AND ECLAIR (E.D.F), - ANALYTICAL STUDIES IN ORDER TO QUALIFY THE CALCULATION CODES. THIS PAPER DESCRIBES THE EXPERIMENTAL PROGRAM AND PRESENTS THE ANALYSIS RESULTS FOR A BENCHMARK TEST.

142. TI - SOME CONSIDERATIONS ON WATER-HAMMER AND CAVITATION FOLLOWING THE SUDDEN CLOSURE OF A CHECK-VALVE.
AU - CAUMETTE, P.; LOTT, M. (CEA-CEN CADARACHE, DRE/STRE, ST-PAUL-LEZ-DURANCE (FRANCE)). WITTMANN, F.H.
PU - P. 45-52. STRUCTURAL MECHANICS IN REACTOR TECHNOLOGY. ACCORD, MA (USA). A.A. BALKEMA PUBLISHERS, 1987.
AB - THE FUNCTION OF A NO-RETURN CHECK-VALVE IS TO OBTURATE A PIPE WHEN THE CURRENT IN IT HAS A TENDANCY TO REVERT: IN NORMAL OPERATION THE VALVE IS MAINTAINED IN OPEN POSITION BY THE FLOW AND IT CLOSES, IN CASE OF FLOW-RATE INVERSION, UNDER THE ACTION OF ITS OWN WEIGHT AND OF THE HYDRODYNAMIC FORCES. AT THE PRECISE TIME OF CLOSURE, THE

STREAM MOST OF THE TIME IS SUDDENLY INTERRUPTED, WHICH DETERMINES A WATER HAMMER AND THE SEPARATION OF A WATER COLUMN FOLLOWED BY OTHER WATER HAMMERS. THE AUTHORS ANALYZE THE MOVEMENT OF A SWING CHECK-VALVE BEFORE CLOSURE AND THE SUBSEQUENT EVOLUTION OF THE FLUID STATE.

143. TI - SHOCK PHENOMENA IN A ONE-COMPONENT TWO-PHASE BUBBLY FLOW, 2. PRESSURE RISE AND PROPAGATION VELOCITY OF PRESSURE WAVES. (IN JAPANESE).
AU - FUJII, TERUSHIGE; AKAGAWA, KOJI (KOBE UNIV. (JAPAN). FACULTY OF ENGINEERING); TSUBOKURA, SADAO; MATSUSHITA, HAJIME.
PU - NIPPON KIKAI GAKKAI RONBUNSHU, B HEN. (NOV 1987). V. 53(495) P. 3193-3198.

144. TI - SOME CONSIDERATIONS ON WATER-HAMMER AND CAVITATION FOLLOWING THE SUDDEN CLOSURE OF A CHECK-VALVE.
AU - CAUMETTE, P.; LOTT, M. (CEA CENTRE D'ETUDES NUCLEAIRES DE CADARACHE, 13 SAINT-PAUL-LES-DURANCE (FRANCE). DEPT. DES REACTEURS A EAU). WITTMANN, F.H. (ED.).
PU - P. 45-51. TRANSACTIONS OF THE 9TH INTERNATIONAL CONFERENCE ON STRUCTURAL MECHANICS IN REACTOR TECHNOLOGY. VOL. F. LWR PRESSURE COMPONENTS. ROTTERDAM (NETHERLANDS). BALKEMA. 1987. 419 P.
AB - THE FUNCTION OF A NO-RETURN CHECK-VALVE IS TO OBTURATE A PIPE WHEN THE CURRENT IN IT HAS A TENDANCY TO REVERT: IN NORMAL OPERATION THE VALVE IS MAINTAINED IN OPEN POSITION BY THE FLOW AND IT CLOSES, IN CASE OF FLOW-RATE INVERSION, UNDER THE ACTION OF ITS OWN WEIGHT AND OF THE HYDRODYNAMIC FROCES. AT THE PRECISE TIME OF CLOSURE, THE STREAM MOST OF THE TIME IS SUDDENLY INTERRUPTED, WHICH DETERMINES A WATERHAMMER AND THE SEPARATION OF A WATER COLUMN FOLLOWED BY OTHER WATERHAMMERS. WE ANALYZE THE MOVEMENT OF A SWING CHECK-VALVE BEFORE CLOSURE AND THE SUBSEQUENT EVOLUTION OF THE FLUID STATE. (ORIG./GL).

145. TI - EXPERIMENTAL AND ANALYTICAL STUDIES ON WATERHAMMER GENERATED BY THE CLOSING OF CHECK VALVES.
AU - HUET, J.L.; GARCIA, J.L. (CEA CENTRE D'ETUDES NUCLEAIRES DE CADARACHE, 13 - SAINT-PAUL-LES-DURANCE (FRANCE). INST. DE RECHERCHE TECHNOLOGIQUE ET DE DEVELOPPEMENT INDUSTRIEL (IRDI); CEA CENTRE D'ETUDES NUCLEAIRES DE CADARACHE, 13 - SAINT-PAUL-LES-DURANCE (FRANCE). DEPT. DES REACTEURS A EAU); COPPOLANI, P. (SOCIETE FRANCO-AMERICAINE DE CONSTRUCTIONS ATOMIQUES (FRAMATOME), 92 - PARIS-LA-DEFENSE (FRANCE)); ZIEGLER, B. (ELECTRICITE DE FRANCE, 77 - ECUELLES). WITTMANN, F.H. (ED.).
PU - P. 25-30. TRANSACTIONS OF THE 9TH INTERNATIONAL CONFERENCE ON STRUCTURAL MECHANICS IN REACTOR TECHNOLOGY. VOL. F. LWR PRESSURE COMPONENTS. ROTTERDAM (NETHERLANDS). BALKEMA. 1987. 419 P.
AB - THE EXPERIMENTAL SERIES PROVIDED AN EXTENSIVE DATA BASE WHICH WAS USED TO QUALIFY THE ANALYSIS CODES AND TO IDENTIFY THE SIGNIFACANT PARAMETERS AFFECTING THE CHECK VALVE BEHAVIOUR AND THE GENERATED WATERHAMMER: OPENING OF THE VALVE AND PRESSURE DROP LAW, GEOMETRY OF THE PIPE (LENGTH, INSIDE DIAMETER), TEST CONDITIONS (PRESSURE, TEMPERATURE). (ORIG./GL).

146. TI - PIPE DYNAMIC LOADING CAUSED BY WATER SLUG FORMATION DUE TO STEAM CONDENSATION.
AU - HENGGE, C.A.; RUPP, C.E.; WILCZYNSKI, D.V. (TOLEDO EDISON CO., OH (USA). NUCLEAR ENGINEERING DIV.). WITTMANN, F.H. (ED.).
PU - P. 33-38. TRANSACTIONS OF THE 9TH INTERNATIONAL CONFERENCE ON STRUCTURAL MECHANICS IN REACTOR TECHNOLOGY. VOL. A. INDEXES, ABBREVIATIONS, SUPPLEMENT. ROTTERDAM (NETHERLANDS). BALKEMA. 1987. 471 P.
AB - THE DAVIS-BESSE NUCLEAR POWER STATION WAS DESIGNED WITH TWO STEAM TURBINE DRIVEN AUXILIARY (EMERGANCY) FEEDWATER PUMTS (AFP). ON JUNE 9, 1985, FOLLOWING A LOSS OF MAIN FEEDWATER, BOTH AFP TURBINES TRIPPED ON OVERSPEED (4500 RPM) APPROXIMATELY 25 SECONDS AFTER INITIATION. THE ROOT CAUSE OF THE OVERSPEED TRIPS WAS DETERMINED TO BE THE INJECTION OF WATER INTO THE AFP TURBINES FROMED BY THE CONDENSATION OF STEAM IN THE TURBINE INLET PIPING. PRIOR TO JUNE 9, 1985, TOLEDO EDISON DISCOVERED DAMAGE TO PIPE SUPPORTS ON THE STEAM INLET LINES. THIS DAMAGE WAS ALSO ATTRIBUTED TO WATER SLUGS CREATED BY STEAM CONDENSATION IN THE LINES. A COMPREHENSIVE TEST PROGRAM HAD BEEN DEVELOPED TO DETERMINE THE TRANSIENT LOADS GENERATED BY THESE WATER SLUGS AND TO IDENTIFY POTENTIAL CORRECTIVE ACTIONS. MODIFICATIONS IMPLEMENTED FOLLOWING THE JUNE 9, 1985 EVENT RESOLVED THE WATER SLUG FORMATION PROBLEM AND ELIMINATED THE NEED TO PERFORM THIS TEST PROGRAM. (ORIG./HP).

147. TI - TRANSID A COMPUTER PROGRAM FOR THE STUDY OF HYDRAULIC TRANSIENTS INVOLVING CAVITATION AND WATERHAMMER.
AU - CAPOZZA, A. (CENTRO INFORMAZIONI STUDI ESPERIENZE, MILAN (ITALY)).
PU - ENERG. NUCL. (ROME). (1986). V. 3(2) P. 105-122.
AB - THE AIM OF THIS PAPER IS A DESCRIPTION AND AN ILLUSTRATION OF THE CAPABILITIES OF THE TRANSID COMPUTER PROGRAM IN ASSISTING THE DESIGN ACTIVITIES OF HYDRAULIC PLANTS. IN FACT, TRANSID IS DEVOTED TO THE ANALYSIS OF HYDRAULIC TRANSIENTS ENTAILING IN CASE CAVITATION AND WATERHAMMER. FIRST A SHORT DESCRIPTION OF THE MAIN FEATURES OF THE ADOPTED MODELS AND NUMERICAL METHODS IS GIVEN, TOGETHER WITH A FEW RESULTS OF THE NECESSARY VALIDATION STUDIES. AFTERWARDS, A FEW SIGNIFICANT EXAMPLES OF TRANSID UTILIZATION FOR THE SAKE OF DESIGN AND COMPLIANCE COMPUTATION ARE SHOWN. FINALLY, CRITICAL REMARKS ABOUT CAPABILITIES AND LIMITS OF THE PROGRAM ARE REPORTED.

148. TI - THE WATERHAMMER ANALYSIS ON CHECK VALVE.
(IN CHINESE).
AU - WANG XIUQING; HE SANYU.
PU - NUCL. POWER ENG. (AUG 1986). V. 7(4) P. 21-27.
AB - THE WATERHAMMER PHENOMENA OF CHECK VALVES IS ANALYSED. THE SOLUTION OF DIFFERENTIAL EQUATION GOVERNING THE MOVING OF VALVE PLATE IS DERIVED. THE FORMULA OF CALCULATING DIMENSIONLESS NUMBER J(T) OF VALVE OPENING IS OBTAINED AND THE WATERHAMMER PRESSURE WAVE ON THE CHECK VALVE IS CALCULATED BY MEANS OF CHARACTERICTIC LINES. THE RESULT SHOWED THAT THE PEAK VALUE OF THE ONLY ONE THIRD OF THAT ON THE HANGING CHECK VALVE. INCREASING LIMIT VALUE OF PLATE ANGLE PHIO AND MOMENT OF INERTIA J ON THE VALVE PLATE CAN RESULT IN THE DECREASING OF WATERHAMMER PRESSURE WAVE PEAK AND CAN RELAX VIBRATION OF THE VALVE PLATE. THE COMPUTATIONAL RESULTS OF WATERHAMMER WAVE CONFORM TO THAT OF THE EXPERIMENT.

149. TI - THE VERTICAL COMPRESSION HAMMER IN HOMOGENEOUS WATER-STEAM CIRCULATION. (IN GERMAN). DER SENKRECHTE VERDICHTUNGSSTOSS IN HOMOGENER WASSER-DAMPF- STROEMUNG.
AU - ROTT, W.
PU - OESTERR. ING.-ARCHIT.-Z. (MAR 1987). V. 132(3) P. 80-84.
AB - A SIMPLE ANALYTICAL MODEL IS PRESENTED OF THE COMPRESSION HAMMER IN WATER-STEAM MIXTURES. IT IS ASSUMED THAT THE STEAM BEHIND THE HAMMER CAN BE COMPLETELY CONDENSED. THE STEADY-STATE SOLUTION IS TECHNICALLY SAFET REGARDING THE DAMAGE POTENTIAL OF FRACTURES IN THE PRESSURE-LEADING PIPE. (AUTH.).

150. TI - SHOCK PHENOMENA IN A ONE-COMPONENT TWO-PHASE BUBBLY FLOW, 1ST REPORT. EXPERIMENTAL RESULTS ON TRANSIENT PRESSURE PROFILES.
AU - FUJII, TERUSHIGE; AKAGAWA, KOJI; TAKENAKA, NOBUYUKI; KOBAYASHI, JUN (KOBE UNIV. (JAPAN). FACULTY OF ENGINEERING); TSUBOKURA, SADAO; HIRAOKA, YOICHI.
PU - BULL. JSME (JPN. SOC. MECH. ENG.). (DEC 1986). V. 29(258) P. 4235-4240.
AB - CHARACTERISTICS OF SHOCK PHENOMENA IN A ONE-COMPONENT TWO-PHASE BUBBLY FLOW INDUCED BY A SUDDEN VALVE CLOSURE AT THE DOWNSTREAM END OF A TEST SECTION ARE INVESTIGATED. AN EXPERIMENT WAS CONDUCTED FOR A TWO-PHASE FLOW IN A HORIZONTAL STAINLESS TUBE OF 21.4 MM ID AND 16.17 M LENGTH WITH A SURGE TANK HAVING A GAS CHAMBER AT THE UPSTREAM END, USING FREON-113 AS THE WORKING FLUID. THE PRESSURE TRANSIENTS ARE PRESENTED AND DISCUSSED QUALITATIVELY. THEY ARE DIFFERENT FROM THOSE OF A TWO-COMPONENT TWO-PHASE FLOW DUE TO THE MASS TRANSFER BETWEEN THE VAPOUR AND THE LIQUID. THE EFFECTS OF FACTORS SUCH AS THE INITIAL VOID FRACTION, THE LIQUID VELOCITY, THE INITIAL PRESSURE, AND THE VALVE CLOSING TIME ON THE PROFILES OF THE TRANSIENT PRESSURE ARE SHOWN. ALSO, THE BEHAVIOURS OF THE VAPOUR BUBBLES AFTER THE VALVE CLOSURE ARE SKETCHED AND EXPLAINED, COMPARING WITH THE PROFILES OF TRANSIENT PRESSURE. (AUTHOR).

151. TI - AN ANALYSIS OF WATER HAMMERING IN BUBBLY FLOWS, 2. TRANSIENT PRESSURE PROFILES IN ONE-COMPONENT FLOWS.
AU - FUJII, TERUSHIGE; AKAGAWA, KOJI (KOBE UNIV. (JAPAN). FACULTY OF ENGINEERING).
PU - BULL. JSME (JPN. SOC. MECH. ENG.). (NOV 1986). V. 29(257) P. 3744-3749.
AB - WATER HAMMER PHENOMENA CAUSED BY A SUDDEN VALVE CLOSURE ARE INVESTIGATED IN ONE-COMPONENT TWO-PHASE FLOWS. THE PHENOMENA IN ONE-COMPONENT TWO-PHASE FLOWS ARE MORE COMPLICATED THAN THOSE IN TWO-COMPONENT TWO-PHASE FLOWS BECAUSE OF THE PRESENCE OF MASS TRANSFER BETWEEN LIQUID AND VAPOUR. BASIC PARTIAL DIFFERENTIAL EQUATIONS BASED ON A ONE-DIMENSIONAL HOMOGENEOUS FLOW MODEL ARE SOLVED ANALYTICALLY BY LINEARIZATION AND ITERATED LAPLACE TRANSFORMATION. THE PROFILE OF THE PRESSURE TRANSIENTS AT THE CLOSING VALVE ARE GIVEN. IT IS SHOWN THAT THE MASS TRANSFER BETWEEN THE TWO PHASES HAS A GREAT INFLUENCE ON THE PROFILE OF THE PRESSURE TRANSIENTS, AND THAT THE MAGNITUDE OF THE INFLUENCE DEPENDS ON THE RELAXATION TIME TAUM OF THE INTERPHASE MASS TRANSFER. (AUTHOR).

152. TI - ANALYSIS OF WATER HAMMERING IN BUBBLY FLOWS. 1. TWO-COMPONENT TWO-PHASE FLOWS.

AU - FUJII, TERUSHIGE; AKAGAWA, KOJI (KOBE UNIV. (JAPAN)).

PU - BULL. JSME (JPN. SOC. MECH. ENG.). (JUN 1986). V. 29(252) P. 1746-1751.

AB - WATER HAMMER PHENOMENA CAUSED BY A SUDDEN VALVE CLOSURE ARE CONSIDERED IN TWO-COMPONENT BUBBLY FLOWS WHERE THE PHENOMENA ARE MORE COMPLICATED THAN IN SINGLE-PHASE FLOWS BECAUSE OF THE PRESENCE OF A COMPRESSIBLE COMPONENT. BASIC PARTIAL DIFFERENTIAL EQUATIONS BASED ON A ONE-DIMENSIONAL HOMOGENEOUS FLOW MODEL ARE SOLVED ANALYTICALLY BY LINEARIZATION AND ITERATED LAPLACE TRANSFORMATION. AS A RESULT, THE PROFILES OF THE PRESSURE TRANSIENTS, THE PROPAGTION VELOCITY OF A PRESSURE WAVE WITH A SMALL AMPLITUDE, AND THE EFFECTS OF VALVE CLOSURE ON TRANSIENT PRESSURES ARE FOUND. FURTHER, THE EFFECT OF FRICTION FACTOR ON PRESSURE PROFILES IS SHOWN AND APPROXIMATED BY A SIMPLE EQUATION. IT IS ALSO SHOWN THAT REFLECTION AND TRANSMISSION OCCUR AT THE INTERPHASE WHERE THE VOID FRACTION CHANGES. (AUTHOR).

153. TI - AN ANALYSIS OF WATER HAMMERING IN BUBBLY FLOWS, (2). TRANSIENT PRESSURE PROFILES IN ONE-COMPONENT FLOWS. (IN JAPANESE).

AU - FUJII, TERUSHIGE; AKAGAWA, KOJI (KOBE UNIV. (JAPAN). FACULTY OF ENGINEERING).

PU - NIPPON KIKAI GAKKAI RONBUNSHU, B HEN. (MAR 1986). V. 52(475) P. 1222-1227.

AB - WATER HAMMER PHENOMENA CAUSED BY A SUDDEN VALVE CLOSURE ARE INVESTIGATED IN ONE-COMPONENT TWO-PHASE FLOWS. THE PHENOMENA IN ONE-COMPNONENT TWO-PHASE FLOWS ARE MORE COMPLICATED THAN THOSE IN TWO-COMPONENT TWO-PHASE FLOWS BECAUSE OF THE PRESENCE OF MASS TRANSFER BETWEEN LIQUID AND VAPOUR. BASIC PARTIAL DIFFERENTIAL EQUATIONS BASED ON A ONE-DIMENSIONAL HOMOGENEOUS FLOW MODEL ARE SOLVED ANALYTICALLY BE LINEARIZATION AND ITERATED LAPLACE TRANSORMATION. THE PROFILES OF THE PRESSURE TRANSIENTS AT THE CLOSING VALVE ARE GIVEN. IT IS SHOWN THAT THE MASS TRANSFER BETWEEN THE TWOPHASES HAS A GREAT INFLUENCE ON THE PROFILE OF THE PRESSURE TRANSIENTS, AND THAT THE MAGNITUDE OF THE INFLUENCE DEPENDS ON THE RELAXATION TIME TAUM OF THE INTERPHASE MASS TRANSFER. (AUTHOR).

154. TI - SHOCK PHENOMENA IN A ONE-COMPONENT TWO-PHASE BUBBLY FLOW, 1. EXPERIMENTAL RESULTS ON TRANSIENT PRESSURE PROFILES. (IN JAPANESE).

AU - AKAGAWA, KOJI; FUJII, TERUSHIGE; TAKENAKA, NOBUYUKI; KOBAYASHI, JUN (KOBE UNIV. (JAPAN). FACULTY OF ENGINEERING); TSUBOKURA, SADAO; HIRAOKA, YOICHI.

PU - NIPPON KIKAI GAKKAI RONBUNSHU, B HEN. (APR 1986). V. 52(476) P. 1865-1871.

AB - THE CHARACTERISTICS OF SHOCKPHENOMENA IN A ONE-COMPONENT TWO-PHASE BUBBLY FLOW INDUCED BY A SUDDEN VALVE CLOSURE AT THE DOWNSTREAM END OF A TEST SECTION ARE INVESTIGATED. AN EXPERIMENT WAS CONDUCTED FOR A TWO-PHASE FLOW IN A HORIZONTAL STAINLESS TUBE OF 21.4 MM ID AND 16.17 M LENGTH WITH A SURGE TANK HAVING A GAS CHAMBER AT THE UPSTREAM END, USING FREON-113 AS THE WORKING FLUID. THE PRESSURE TRANSIENTS ARE PRESENTED AND DISCUSSED QUALITATIVELY. THEY ARE DIFFERENT FROM THOSE OF TWO-COMPONENT TWO-PHASE FLOW DUE TO THE MASS

TRANSFER BETWEEN THE VAPOUR AND THE LIQUID. THE EFFECTS OF EACH FACTER SUCH AS THE INITIAL VOID FRACTION, THE LIQUID VELOCITY, THE INITIAL PRESSURE, AND THE VALVE CLOSING TIME, ON THE PROFILES OF THE TRANSIENT PRESSURE ARE SHOWN. ALSO, THE BEHAVIOURS OF THE VAPOUR BUBBLES AFTER VALVE CLOSURE ARE SKETCHED AND EXPLAINED, AND ARE COMPARED WITH THE PROFILES OF TRANSIENT PRESSURE. (AUTHOR).

155. TI - FLUID-STRUCTURE INTERACTION IN WATERHAMMER RESPONSE OF FLEXIBLE PIPING.
AU - BELYTSCHKO, T.; KARABIN, M.; LIN, J.I. (DEPT. OF CIVIL ENGINEERING, NORTHWESTERN UNIV., EVANSTON, IL 60201).
PU - J. PRESSURE VESSEL TECHNOL. (AUG 1986). V. 108(3) P. 249-255.
AB - IN THE WATERHAMMER ANALYSIS OF PIPING SYSTEMS, INCOMPRESSIBLE (OR ADDED MASS) REPRESENTATIONS ARE GENERALLY USED IN COMPUTING THE RESPONSE OF THE PIPING. IT IS SHOWN THAT THIS PROCEDURE IS NOT NECESSARILY CONSERVATIVE, PARTICULARLY FOR THIN-WALLED, FLEXIBLE PIPING SYSTEMS, AND THAT FULLY COUPLED FLUID-STRUCTURE SOLUTIONS CAN PREDICT HIGHER LOADS AND STRESSES. A MODAL RECOVERY PROCEDURE WHICH EASILY PERMITS THE REPRESENTATION ON THE ACOUSTIC EFFECTS OF THE FLUID TO BE INCLUDED IN A STRUCTURAL MODEL IS ALSO PRESENTED. RESULTS ARE GIVEN FOR BOTH SIMPLE MODELS AND A PIPING SYSTEM FROM AN LMFBR DESIGN.

156. TI - WATER-HAMMER EXPERIMENTAL SET-UP AND WATER-HAMMER EXPERIMENTAL STUDY FOR NEW TYPES OF CHECK VALVE APPLIED TO PWR. (IN CHINESE).
AU - LIU HANXUN.
PU - NUCL. POWER ENG. (JUN 1985). V. 6(3) P. 28-35.
AB - THIS PAPER DESCRIBES A SELF-DESIGNED CONSTANT TEMPERATURE WATER-HAMMER SHOCK TEST RIG WITH STAINLESS STEEL LOOP IN WHICH DEIONIZED WATER IS USED AS WORKING MEDIUM. TO CONDUCT WATER-HAMMER SHOCK SIMULATION TESTS FOR THE COUNTERCURRENT PHENOMENON OCCURRED IN THE PROCESS OF SHUTTING, STOPPING, PARALLELLING AND SWITCHING THE COOLANT LOOPS OF NUCLEAR REACTOR, A SPECIALLY DESIGNED FOUR-WAY SWITCHING VALVE AND ITS PNEUMATIC MECHANISM ARE USED. WATER-HAMMER EXPERIMENTAL STUDY IS PERFORMED FOR TWO TYPES OF PWR'S NONSHOCK CHECK VALVE WITH DIAMETER OF 150 MM AND 200 MM SIMULTANEOUSLY. TRANSIENT PERFORMANCE OF THE SHOCK WAVES, MAGNITUDE OF THEIR PEAKS AND DURATIONS OF THEIR FLUCTUATION, IS OBTAINED. SOME ANALYSES FOR EXISTING CALCULATIONAL METHOD ON WATER-HAMMER ARE MADE.

157. TI - ANALYSIS OF WATER HAMMERING IN BUBBLY FLOWS, (1). TWO-COMPONENT TWO-PHASE FLOWS. (IN JAPANESE).
AU - FUJII, TERUSHIGE; AKAGAWA, KOJI (KOBE UNIV. (JAPAN). FACULTY OF ENGINEERING).
PU - NIPPON KIKAI GAKKAI RONBUNSHU, B HEN. (OCT 1985). V. 51(470) P. 3360-3365.
AB - WATER HAMMER PHENOMENA CAUSED BY A SUDDEN VALVE CLOSURE ARE CONSIDERED IN TWO-COMPONENT BUBBLY FLOWS WHERE THE PHENOMENA ARE MORE COMPLICATED THAN THOSE IN SINGLE-PHASE FLOWS BECAUSE OF THE PRESENCE OF THE COMPRESSIBLE COMPONENT. BASIC PARTIAL DIFFERENTIAL EQUATIONS BASED ON A ONE-DIMENSIONAL HOMOGENEOUS FLOW MODEL ARE SOLVED ANALYTICALLY BY LINEARIZATION AND ITERATED LAPLACE TRANSFORMATION. AS A RESULT, THE PROFILES OF THE PRESSURE TRANSIENTS, THE PROPAGATION VELOCITY OF A PRESSURE WAVE WITH A SMALL

AMPLITUDE, AND THE EFFECTS OF VALVE CLOSURE ON TRANSIENT PRESSURES ARE FOUND. FURTHER, THE EFFECT OF FRICTION FACTOR ON PRESSURE PROFILES IS SHOWN AND APPROXIMATED BY A SIMPLE EQUATION. IT IS ALSO SHOWN THAT REFLECTION AND TRANSMISSION OCCUR AT THE INTERPHASE WHERE THE VOID FRACTION CHANGES. (AUTHOR).

158. TI - FLOW OSCILLATIONS INDUCED BY INJECTION OF SUBCOOLED WATER INTO STEAM FLOW IN HORIZONTAL PIPE. CLASSIFICATION OF PHENOMENA AND THRESHOLD OF OSCILLATION OCCURRENCE. (IN JAPANESE).
AU - AYA, IZUO (SHIP RESEARCH INST., TOKYO (JAPAN)); NARIAI, HIDEKI. 5713000
PU - NIPPON KIKAI GAKKAI RONBUNSHU, B HEN. (JAN 1985). V. 51(461) P. 185-194.

159. TI - STEAM HAMMER ANALYSIS APPLIED TO THE MAIN STEAM PIPING SYSTEM OF A CANDU NUCLEAR GENERATING STATION.
AU - MIKASINOVIC, M.; MARUCCI, P.A. (ONTARIO HYDRO, TORONTO (CANADA). MECHANICAL DESIGN DEPT.).
STALPAERT, J. (ED.).
PU - P. 73-78. TRANSACTIONS OF THE 8. INTERNATIONAL CONFERENCE ON STRUCTURAL MECHANICS IN REACTOR TECHNOLOGY. VOL. F1 AND F2. VOL. F1: LWR PRESSURE COMPONENTS - CORE STRUCTURES, PIPING AND VESSELS. VOL. F2: LWR PRESSURE COMPONENTS - EFFECT OF ENVIRONMENT ON MATERIALS AND STRUCTURES. AMSTERDAM (NETHERLANDS). NORTH-HOLLAND. 1985. 547 P.

160. TI - INVESTIGATION OF A PIPE SYSTEM UNDER DYNAMIC LOADS.
AU - SIEBLER, T. (KERNFORSCHUNGSZENTRUM KARLSRUHE G.M.B.H. (GERMANY, F.R.). PROJEKTBEREICH HEISSDAMPFREAKTOR - SICHERHEITSPROGRAMM); STRAUB (STUTTGART UNIV. (GERMANY, F.R.). INST. FUER STATIK UND DYNAMIK DER LUFT-UND RAUMFAHRTKONSTRUKTIONEN); SCHRADER, W. (KRAFTWERK UNION A.G., OFFENBACH AM MAIN (GERMANY, F.R.)); DIEM, H. (STUTTGART UNIV. (GERMANY, F.R.). STAATLICHE MATERIALPRUEFUNGSANSTALT). 9202032; 9200465; 9200943; 6011360
STALPAERT, J. (ED.).
PU - P. 169-173. TRANSACTIONS OF THE 8. INTERNATIONAL CONFERENCE ON STRUCTURAL MECHANICS IN REACTOR TECHNOLOGY. VOL. F1 AND F2. VOL. F1: LWR PRESSURE COMPONENTS - CORE STRUCTURES, PIPING AND VESSELS. VOL. F2: LWR PRESSURE COMPONENTS - EFFECT OF ENVIRONMENT ON MATERIALS AND STRUCTURES. AMSTERDAM (NETHERLANDS). NORTH-HOLLAND. 1985. 547 P.

161. TI - PROPAGATION OF PRESSURE WAVES THROUGH AIR-WATER MIXTURES.
AU - JAKEMAN, D.; SMITH, B.L.; HEER, W.
OR - EIDGENOESSISCHES INST. FUER REACTORFORSCHUNG, WUERENLINGEN, SWITZERLAND
PU - NOV 1984. 44 P.

162. TI - WATER HAMMER, FLOW INDUCED VIBRATION AND SAFETY/RELIEF VALVE LOADS.
AU - VALANDANI, P.; UFFER, R.; SEXTON, D.
OR - QUADREX CORP., CAMPBELL, CAN(USA). 9515191
PU - SEP 1984. 79 P.

163. TI - INVESTIGATION OF COLD LEG WATER HAMMER IN A PWR DUE TO THE ADMISSION OF EMERGENCY CORE COOLING (ECC) DURING A SMALL BREAK LOCA.
AU - JACKOBEK, A.B.; GRIFFITH, P.

OR - MASSACHUSETTS INST. OF TECH., CAMBRIDGE (USA). DEPT. OF MECHANICAL ENGINEERING. 3977000
PU - SEP 1984. 59 P.

164. TI - WATER HAMMER IN THE CIRCULATING PIPE LINE WITH PRESSURE VESSELS. (IN JAPANESE).
AU - KATO, EIJI; SUITA, MINORU; KAWAMATA, MASAAKI (IBARAKI UNIV., HITACHI (JAPAN). FACULTY OF ENGINEERING); YUDA, MASUMI. 3080500
PU - NIPPON KIKAI GAKKAI RONBUNSHU, B HEN. (OCT 1983). V. 49(446) P. 2236-2241.

165. TI - MODAL SPECTRUM ANALYSIS OF PIPING SYSTEMS UNDER WATER-HAMMER LOADING: SPECTRA EXAMINATION.
AU - MEDER, G.; GRAMS, J. (BROWN, BOVERI UND CIE A.G., MANNHEIM (GERMANY, F.R.). ABT. GK/TE).
OR - COMMISSION OF THE EUROPEAN COMMUNITIES, LUXEMBOURG; ARGONNE NATIONAL LAB., IL (USA). 1910850; 0448000
PU - P. 283-289. TRANSACTIONS OF THE 7. INTERNATIONAL CONFERENCE ON STRUCTURAL MECHANICS IN REACTOR TECHNOLOGY. VOL. F. LWR PRESSURE COMPONENTS - CORE STRUCTURES AND PIPING. AMSTERDAM (NETHERLANDS). NORTH-HOLLAND. 1983. 426 P.

166. TI - DEVELOPMENT OF METHODOLOGIES FOR COUPLED WATER-HAMMER ANALYSIS OF PIPING SYSTEMS AND SUPPORTS.
AU - KAMIL, H.; GANTAYAT, A. (ENGINEERING DECISION ANALYSIS CO., PALO ALTO, CA (USA)); ATTIA, A. (PHYSICS INTERNATIONAL CO., SAN LEANDRO, CA (USA)); GOULDING, H. (ONTARIO HYDRO, TORONTO (CANADA)). 9508510; 5203000; 4939760
OR - COMMISSION OF THE EUROPEAN COMMUNITIES, LUXEMBOURG; ARGONNE NATIONAL LAB., IL (USA). 1910850; 0448000
PU - P. 275-281. TRANSACTIONS OF THE 7. INTERNATIONAL CONFERENCE ON STRUCTURAL MECHANICS IN REACTOR TECHNOLOGY. VOL. F. LWR PRESSURE COMPONENTS - CORE STRUCTURES AND PIPING. AMSTERDAM (NETHERLANDS). NORTH-HOLLAND. 1983. 426 P.

167. TI - CALCULATION OF FLUID (STEAM) HAMMER LOADING TO PIPING SYSTEMS BY THE RESPONSE SPECTRUM METHOD.
AU - KRAUSE, G. (INGENIEURBUERO FUER STRUKTURANALYSE, HEDDESHEIM (GERMANY, F.R.)); SCHRADER, W. (KRAFTWERK UNION A.G., OFFENBACH AM MAIN (GERMANY, F.R.)); LEIMBACH, K.R. ; 9200943
OR - COMMISSION OF THE EUROPEAN COMMUNITIES, LUXEMBOURG; ARGONNE NATIONAL LAB., IL (USA). 1910850; 0448000
PU - P. 265-274. TRANSACTIONS OF THE 7. INTERNATIONAL CONFERENCE ON STRUCTURAL MECHANICS IN REACTOR TECHNOLOGY. VOL. F. LWR PRESSURE COMPONENTS - CORE STRUCTURES AND PIPING. AMSTERDAM (NETHERLANDS). NORTH-HOLLAND. 1983. 426 P.

168. TI - INFLUENCE OF FLUIDDYNAMIC PARAMETERS UPON FLUID-HAMMER FORCES AND SPECTRA.
AU - MEDER, G.; GRAMS, J. (BROWN, BOVERI UND CIE A.G., MANNHEIM (GERMANY, F.R.)). 0951000
PU - NUCL. ENG. DES. (JAN 1984). V. 77(1) P. 7-21.

169. TI - STRAIN ON PIPE WALLS RESULTING FROM WATER HAMMER. (IN GERMAN). BEANSPRUCHUNG DER ROHRWANDUNG INFOLGE VON DRUCKSTOESSEN.
AU - BUERMANN, W. (KARLSRUHE UNIV. (T.H.) (GERMANY, F.R.). INST. FUER HYDROMECHANIK). 9200545
PU - 3 R INT. (SEP 1983). V. 22(9) P. 426-431.

170. TI - SPECTRA METHODS FOR ANALYSIS OF PIPING SYSTEMS UNDER FLUID HAMMER LOADINGS. (IN GERMAN). DYNAMISCHE DRUCKSTOSSBERECHNUNG VON ROHRLEITUNGEN MIT ANTWORTSPEKTREN.
AU - MEDER, G. (BROWN, BOVERI UND CIE A.G., MANNHEIM (GERMANY, F.R.). ABT. GK/TE); RICK, K. (MATHEMATISCHER BERATUNGS- UND PROGRAMMIERUNGSDIENST G.M.B.H., DORTMUND (GERMANY, F.R.)). ;
PU - 3 R INT. (SEP 1983). V. 22(9) P. 414-426.

171. TI - EVALUATION OF WATER HAMMER POTENTIAL IN PREHEAT STEAM GENERATORS.
AU - SEXTON, D.E.; KASAHARA, M.; UFFER, R.A.
OR - QUADREX CORP., CAMPBELL, CA (USA). 9515191
PU - DEC 1982. 38 P.

172. TI - STUDIES OF SHOCK PHENOMENA IN TWO-PHASE FLOW, (2). CHARACTERISTICS IN SLUG FLOW REGION. (IN JAPANESE).
AU - AKAGAWA, KOJI; FUJII, TERUSHIGE; FUKUHARA, KAZUYA (KOBE UNIV. (JAPAN). FACULTY OF ENGINEERING); ITO, YUTAKE; YAMAGUCHI, TOSHIAKI. 3630100
PU - NIPPON KIKAI GAKKAI RONBUNSHU, B HEN. (JUL 1981). V. 47(419) P. 1287-1297.

173. TI - COMPILATION OF DATA CONCERNING KNOW AND SUSPECTED WATER HAMMER EVENTS IN NUCLEAR POWER PLANTS, CY 1969.
AU - CHAPMAN, R.L.; CHRISTENSEN, D.D.; DAFOE, R.E.; HANNER, O.M.; WELLS, M.E.
OR - EG AND G IDAHO, INC., IDAHO FALLS (USA). 9507781
PU - MAY 1981. 294 P.

174. TI - PRESSURE AND FLUID OSCILLATION INDUCED BY INJECTION OF SUBCOOLED WATER INTO STEAM FLOW. (IN JAPANESE).
AU - AYA, I.; KOBAYASHI, M.; INASAKA, F. (SHIP RESEARCH INST., TOKYO (JAPAN)); NARIAI, H. 5713000
PU - NIPPON DENNETSU SHINPOJIUMU KOEN RONBUNSHU. (1981). (NO.18) P. 133-135.

175. TI - AN EFFICIENT PROCEDURE FOR EVALUATING DYNAMIC RESPONSES OF PIPING SYSTEMS TO WATER/STEAM HAMMER EVENTS.
AU - YEH, G.C.K.; HOH, F.K.C. (BECHTEL POWER CORP., LOS ANGELES, CA (USA)).
OR - SOCIETE FRANCAISE D'ENERGIE NUCLEAIRE (SFEN), 75 - PARIS; COMMISSION OF THE EUROPEAN COMMUNITIES, BRUSSELS (BELGIUM). 9100680; 1910600
PU - P. STRUCTURAL MECHANICS IN REACTOR TECHNOLOGY. VOL. F. STRUCTURAL ANALYSIS OF THERMAL REACTOR CORE AND COOLANT CIRCUIT STRUCTURE. AMSTERDAM, NETHERLANDS. NORTH-HOLLAND PUBLISHING CO. 1981. 332 P.

176. TI - PRESSURE TRANSIENT PROPAGATION IN FILLING PIPES.
AU - YOUNGDAHL, C.K.; KOT, C.A. (ARGONNE NATIONAL LAB., IL (USA).

COMPONENTS TECHNOLOGY DIV.).
OR - SOCIETE FRANCAISE D'ENERGIE NUCLEAIRE (SFEN). 75 - PARIS; COMMISSION OF THE EUROPEAN COMMUNITIES. BRUSSELS (BELGIUM). 9100680; 1910600
PU - VP. STRUCTURAL MECHANICS IN REACTOR TECHNOLOGY. VOL. B. THERMAL AND FLUID - STRUCTURE DYNAMICS ANALYSIS. AMSTERDAM. NETHERLANDS. NORTH-HOLLAND PUBLISHING CO. 1981. 280 P.

177. TI - PIPING RESPONSE TO STEAM-GENERATED WATER HAMMER.
AU - GRUEL. R.L.; HUBER. P.W.; HURWITZ. W.M. (MIT. CAMBRIDGE. MASS. USA).
PU - J. PRESSURE VESSEL TECHNOL. (AUG 1981). V. 103(3) P. 219-225.
TI - MATCH HYDRAULIC-TRANSIENT ANALYSIS TO POWER PLANT WATER-SYSTEM NEEDS. (PWR;BWR.)
AU - O'KEEFE. W.
PU - POWER. (AUG 1981). V. 125(8) P. 73-75.

178. TI - THEORETICAL CALCULATION POSSIBILITIES OF THE COMPUTER CODE HAMMER. (IN PORTUGUESE). POSSIBILIDADES TEORICAS DE CALCULO DO PROGRAMA DE COMPUTACAO HAMMER.
AU - ONUSIC JUNIOR. J.
OR - INSTITUTO DE ENERGIA ATOMICA. SAO PAULO (BRAZIL). TESE (M.SC.). 3267000
PU - JUN 1978. 72 P.

179. TI - WATER-HAMMER IN THE FEED-WATER PIPES FOR PWR STEAM GENERATORS. (IN FRENCH). COUPS DE BELIER DANS LES TUYAUTERIES D'EAU ALIMENTAIRE DES GENERATEURS DE VAPEUR DES CENTRALES A EAU PRESSURISEE.
AU - GONNET. BERNARD; LEROY. CLAUDE; OULLION. JEAN; YAZIDJIAN. J.-C. (SOCIETE FRANCO-AMERICAINE DE CONSTRUCTIONS ATOMIQUES (FRAMATOME). 92 - COURBEVOIE (FRANCE)). 5787700
PU - HOUILLE BLANCHE. (1979). V. 34(2-3) P. 135-142.

180. TI - CONDENSATION INDUCED WATER HAMMER IN STEAM GENERATORS.
AU - JONES. O.C. JR.; SAHA. P.; WU. B.J.C.; GINSBERG. T.
OR - BROOKHAVEN NATIONAL LAB.. UPTON. NY (USA). 0936000
PU - JUN 1979. 19 P.

181. TI - DYNAMIC SHOCK WAVE: HAMMER BLOW. (IN FRENCH). ONDES DE CHOC DYNAMIQUES: COUP DE BELIER.
AU - LACKME. CLAUDE (CEA CENTRE D'ETUDES NUCLEAIRES DE GRENOBLE. 38 (FRANCE). SERVICE DES TRANSFERTS THERMIQUES). 1394000
PU - P. 177-192. NON STATIONARY THERMAL AND HYDRAULIC PHENOMENA. PROCEEDINGS OF THE SUMMER SCHOOL ON FLUID MECHANICS. JOUY-EN-JOSAS. 10-15 OCTOBER 1976. (PHENOMENES THERMIQUES ET HYDRAULIQUES NON STATIONNAIRES. COMPTE RENDU DE L'ECOLE D'ETE DE MECANIQUE DES FLUIDES. JOUY-EN-JOSAS. 10-15 OCTOBRE 1976.) PARIS. FRANCE. EYROLLES. 1978.

182. TI - PIPE RUPTURE AND STEAM/WATER HAMMER DESIGN LOADS FOR DYNAMIC ANALYSIS OF PIPING SYSTEMS.
AU - STRONG. B.R. JR.; BASCHIERE. R.J. (ADVANCED ANALYSIS DIVISION. EDS NUCLEAR INC.. 220 MONTGOMERY STREET. SAN FRANCISCO. CALIFORNIA 94104. U.S.A.). JAEGER. T.A.; BOLEY. B.A. (EDS.).
OR - INTERNATIONAL ASSOCIATION FOR STRUCTURAL MECHANICS IN REACTOR TECHNOLOGY; COMMISSION OF THE EUROPEAN COMMUNITIES. BRUSSELS

(BELGIUM). 3293060; 1910600
PU - V. F P. F4/3. STRUCTURAL MECHANICS IN REACTOR TECHNOLOGY. TRANSACTIONS OF THE 4TH INTERNATIONAL CONFERENCE HELD IN SAN FRANCISCO, USA, 15 - 19 AUG 1977. AMSTERDAM, NETHERLANDS. NORTH-HOLLAND. 1977.

183. TI - STEAMHAMMER IN MAIN STEAM PIPING SYSTEMS.
(IN GERMAN). DRUCKSTOESSE IN FRISCHDAMPFLEITUNGEN.
AU - DITTMAR, H. (PREUSSISCHE ELEKTRIZITAETS-A.G. (PREUSSENELEKTRA), HANNOVER (GERMANY, F.R.)); MUNCACIU, D.; THIES, J. (MOTOR-COLUMBUS INGENIEURUNTERNEHMUNG A.G., BADEN (SWITZERLAND)). 5298300; 4344700 JAEGER, T.A.; BOLEY, B.A. (COMPS.).
PU - 1977. F 6/9, 11 P. TRANSACTIONS OF THE 4TH INTERNATIONAL CONFERENCE ON STRUCTURAL MECHANICS IN REACTOR TECHNOLOGY. SAN FRANCISCO, CALIF., USA, 15-19 AUGUST 1977. V. F.

184. TI - PIPE RUPTURE AND STEAM/WATER HAMMER DESIGN LOADS FOR DYNAMIC ANALYSIS OF PIPING SYSTEMS.
AU - STRONG, B.R. JR.; BASCHIERE, R.J. (ADVANCED ANALYSIS DIVISION, EDS NUCLEAR INC., SAN FRANCISCO, CALIF., USA). JAEGER, T.A.; BOLEY, B.A. (COMPS.).
PU - 1977. F 4/3, 1 P. TRANSACTIONS OF THE 4TH INTERNATIONAL CONFERENCE ON STRUCTURAL MECHANICS IN REACTOR TECHNOLOGY. SAN FRANCISCO, CALIF., USA, 15-19 AUGUST 1977. V. F.

185. TI - EVALUATION OF PWR STEAM GENERATOR WATER HAMMER. FINAL TECHNICAL REPORT, JUNE 1, 1976--DECEMBER 31, 1976.
AU - BLOCK, J.A.; CROWLEY, C.J.; ROTHE, P.H.; WALLIS, G.B.; YOUNG, L.R.
OR - CREARE, INC., HANOVER, N.H. (USA). 9500719
PU - MAY 1977. 329 P.

186. TI - DEVELOPMENT OF AN ANALYSIS CODE FOR PRESSURE WAVE PROPAGATION, (1). ANALYSES OF EXPERIMENT.
AU - TANAKA, YOSHIHISA; SAKANO, KOSUKE; SHINDO, YOSHIHISA (KAWASAKI HEAVY INDUSTRIES, LTD., KOBE (JAPAN)). 3532600
OR - POWER REACTOR AND NUCLEAR FUEL DEVELOPMENT CORP., TOKYO (JAPAN). 5285200
PU - NOV 1974. 48 P.

187. TI - QUAD-CITIES STATION, UNIT 1. ABNORMAL OCCURRENCE 1-72-4, WATER HAMMER DAMAGED SPRAY SYSTEM.
OR - COMMONWEALTH EDISON CO., CORDOVA, ILL. (USA). 1912500
PU - 5 APR 1972. 1 P.

188. TI - DRESDEN NUCLEAR POWER STATION, UNIT 2. HYDRAULIC SHOCK TO THE SHUTDOWN COOLING SYSTEM.
OR - COMMONWEALTH EDISON CO., CHICAGO, ILL. (USA). 1912000
PU - 1 NOV 1971. 11 P.

189. TI - SURGE AND WATER HAMMER PROBLEMS IN THE COOLING WATER SYSTEM OF LARGE THERMAL POWER PLANTS.
AU - JANSA, B. (VATTENBYGGNADSBYRAAN, GOETEBORG (SWEDEN)). 6674250
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